ENERGY MANAGEMENT

TRAINING MATERIAL

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CHAPTER 1

WORLD ENERGY SCENE

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No single subject has so dominated post-war politics as energy, since it is the basic input in the production process. Over time, with economic development, there has been a significant increase in the per capita consumption of energy. This led to the belief that an increase in energy consumption was a prerequisite to economic development. However, this linking of economic development with increased energy usage has over the years led to an irrational increase in energy consumption.

The sudden rise in oil prices in 1973-74, only served to emphasize the degree of interdependence among nations. Consequent to the energy crises of the early and late seventies, a delinking of economic growth and energy use was attempted in developed countries. Efforts in this direction have borne fruit to the extent that energy consumption has been curtailed in the developed countries. The notable achievements were in Japan and the EEC member states. A similar trend is not evident in the developing countries.

Since energy resources are spread unevenly throughout the world, different countries approach the energy crisis in different ways. Some of the developed countries, with a sound technology base, lack the easy accessibility to energy sources that a few of the developing oil-producing countries have. The latter group of countries often face a paucity of technological know-how necessary for economic development.

Given the importance of energy in the world, and the fact that resources are limited and unevenly distributed, a review of the current energy scenario assumes importance.

In addition, over the last few years, the negative impacts of energy use on the environment have assumed considerable importance. This has led to many research studies, increased emphasis on energy conservation, and a greater use of renewable energy sources, though limited in application.

It is difficult to relate energy consumption levels with 'quality of life'. Energy requirements in any society would depend on the level of material comforts and activities including travel, sports, recreation, etc. There is a tendency to link material comforts with quality of life, which may be argued against by those who believe that these are based on the needs of an individual/family/society and what it considers as minimum levels of comfort. However, there is no doubt that man has certain basic needs and that energy is essential to satisfy these.

For many years (until about 1980) it was assumed that higher levels of energy consumption were indicative of a better standard of living. This was until nations realized that energy could be saved by using it more efficiently for all human activities. In recent years, Japan and western Europe have clearly demonstrated that energy demand and economic development (normally measured by GDP growth) could be partially decoupled. Therefore, it is no longer believed that for GDP growth, energy consumption has to increase proportionately.

The present day environmental concerns are forcing nations to cut down on energy consumption, especially that of fossil fuels. It is believed that this would force people to modify the way they live in many countries. The primary goal in any development strategy would be sustainability of resources.

It would be inappropriate to compare per capita energy consumption levels in developing countries such as India with those of developed countries such as the United States. Though some of the energy consumption in U.S.A. is superfluous and more a result of conspicuous and wasteful consumption rather than need-based consumption, the higher energy consumption level is indicative of a better material standard of living. However, aesthetically the level of energy consumption is not a reliable indicator of quality of life.

1.1 RESERVES

1.1.1 Oil

The proven oil reserves of the world at the end of 1988 stood at 123.8 billion tonnes. The distribution of these reserves was as follows: Saudi Arabia 18.6 per cent, Iraq 10.9 per cent, Iran 10.1 per cent, Abu Dhabi 10.1 per cent, Kuwait 10.0 per cent, and others 40.3 per cent.

The total reserves of the Middle East countries amounted to 62.3 per cent. The next largest share of reserves lay with the Latin American countries, with Venezuela and Mexico accounting for most of the reserves.

The reserves/production ratio gives the length of time the reserves could be expected to last at the current level of production. The reserves/production ratio for the world stood at 41 years in 1988. A look at the reserves/production ratio of individual country blocs reveals that reserves will last in the Middle East for about 108 years, in Latin America for about 51 years, in Africa for about 10 years and in Western Europe for about 12 years.

Table 1 gives the details of world oil production over the period 1978-88. Among the various groups of countries, the socialist bloc contributed about a quarter to the total world oil production in 1988. The contribution of the Middle East was approximately the same. This was followed by contributions of 18 and 11 per cent from North America and Latin America respectively.

From the production trends over the decade, it is observed that the output decreased drastically in the Middle East in 1979-80 and again in 1980-81 consequent to the Iranian revolution and the Iran-Iraq War. During the same time period, production dipped in North America and Africa too. For all other country blocs, however, production increased steadily over the decade.

As regards individual countries, the main oil producers in 1988 were USSR (21 per cent), USA (15 per cent) and Saudi Arabia (9 per cent).

Table 1

World Oil Production

Country Bloc	1978 (Mt)	1983 (Mt)	1988 (Mt)	Change from '87 to '88 (%)	Share of Total(%) (1988)
N.America	562.5	558.5	545.9	-1.0	18.1
L.Amercia	251.4	326.1	341.0	+3.4	11.3
W.Europe	85.5	168.4	198.0	-0.5	6.5
Middle East	1058.8	595.6	739.3	14.8	24.3
Africa	295.9	227.0	262.5	+5.0	8.7
Asia & Australasia	137.0	144.7	162.8	+1.6	5.3
Socialist Countries	701.8	746.1	781.3	+0.3	25.8
Total	3092.9	2766.4	3030.8	+4.0	100.0

Table 2 shows the world oil consumption levels in 1978, 1983 and 1988. The consumption figures include inland demand plus international aviation, marine bunkers, and refinery fuel and losses. A look at the oil consumption trends over the years indicates that the consumption levels dropped sharply in the early '80s in most of the developed countries of North America, Western Europe, South-East Asia, Australasia and in Japan. This could be

due to the steep rise in oil prices during this period consequent to the Iranian revolution and the Iran-Iraq war. However, with oil prices dropping in recent years, oil consumption has shown an increase. The developing economies of the Middle East, Africa, South Asia and the socialist bloc countries have continued to increase their oil consumption over the period, but at a much slower rate.

Table 2

World Oil Consumption

Country Bloc	1978 (Mt)	1983 (Mt)	1988 (Mt)	Change from '87 to '88 (%)	Share of Total(%) (1988)
N.America	975.7	773.1	863.9	+3.5	28.5
L.Amercia	191.2	211.0	228.1	+1.5	19.5
W.Europe	700.0	571.7	594.1	+1.8	7.5
Middle East	85.5	118.0	135.4	+4.1	4.5
Africa	62.8	78.9	86.2	+1.1	2.8
Asia & Australasia	434.9	398.4	465.9	+10.0	15.3
Socialist Countries	634.3	646.2	664.9	+0.2	21.9
Total	3084.4	2797.3	3038.5	+3.1	100.0

Among the top five oil consuming countries, USA, Japan and West Germany consumed far greater quantities than they produced. (See Table 3 for details).

Table 3

Oil Consumption in Major Countries

(Mt)

Country	Production	Consumption
China	136.1	100.7
West Germany	3.9	114.8
Japan	0.7	222.2
USSR	624.0	439.1
USA	462.5	789.2

Given the fact that the oil reserves are unevenly distributed ovcr the world and that there are differences in the demand in various countries, the oil movement is an aspect which merits consideration. Since this affects the balance of payment of any country, it can trigger off a multitude of effects on the economy. Table 4 illustrates this point clearly.

Table 4

World Imports and Exports of Oil in 1988

(Mt)

Country Bloc	Crude Import	Product Import	Crude Export	Product Export	Net Crude Import	Net Product Import	Total Import
N.America	263.3	92.6	32.9	34.9	230.3	57.7	288.0
L.Amercia	30.3	20.8	106.3	44.5	-76.0	-23.7	-99.7
W.Europe	355.3	91.7	27.2	24.5	328.1	67.2	395.8
Middle East	0.7	2.0	510.0	85.5	-500.3	-83.5	-583.8
Africa	21.0	7.1	191.3	34.6	-170.3	-27.5	-197.8
Asia & Australasia	281.4	91.4	46.4	29.8	235.0	61.6	296.6
Socialist Countries	51.3	4.6	106.1	79.9	-54.8	-75.3	-130.1
Destination not known	8.0	23.5	-	-	8.0	23.5	31.5
Total	1011.2	333.7	1011.2	333.7	-	-	-

The above table reveals that three groups of countries, namely North America, Western Europe, and Asia and Australasia, were the primary importers of oil in 1988. The pattern of petroleum and petroleum products imports reveals that in these three blocs the petroleum crude imports were much higher than those of petroleum products, by 2.8, 3.9 and 3.1 tonnes respectively. Within the region of Asia and Australasia, Japan accounted for about 73 per cent of the net imports to the region.

Corresponding to the production and imports, the requisite support structure in terms of refinery capacity is essential. Table 5 compares the total requirement (production plus net imports) with refinery capacity.

Petroleum Refining Capacity in 1988

(Mt)

Country Bloc	Production	Total Imports	Total Refinery Requirement	Refining Capacity	Capacity Requirement (tonne)
N.America	545.9	288	833.9	880	1.06
L.Amercia	341.0	-99.7	241.3	370	1.53
W.Europe	198.0	395.3	593.3	690	1.16
Middle East	739.3	-583.8	155.5	220	1.41
Africa	262.5	-197.8	64.7	130	2.01
Asia & Australasia	162.8	296.6	459.4	500	1.09
Socialist Countries	781.3	130.1	651.2	890	1.37
Total			2999.3	3690	

Analysis reveals that for 1988, all regional country blocs had excess refinery capacity. While Africa had a capacity twice that of its net requirement, Latin America had a capacity 1.5 times that of its requirement. Others had varying ratios of refinery capacity to actual requirement, ranging from 1.06 times to 1.41 times.

1.1.2 Coal

It was only in recent years that oil replaced coal as the major primary energy source. Coal has been in use for a long time and its availability was one of the forces behind the Industrial Revolution.

Compared to oil reserves, coal reserves are expected to last much longer. The maximum reserves (47.7 per cent) lie with the socialist countries, followed by North America (26.3 per cent). Considering individual countries, the bulk of the reserves lies with USA (26 per cent of the total), USSR (24 per cent) and China (16 per cent). Table 6 gives details of anthracite and bituminous, and sub-bituminous and lignite reserves in 1988. At the current levels of consumption, the world reserves of coal are expected to last around 181 years. These reserves are expected to last longest in Latin America followed by Africa, and the least in Western Europe. (This is indicated by the reserves to production (R/P) ratio in Table 6).

Table 6

Coal Reserves at End of 1988

Country Bloc	Anthracite & Bituminous (Mtoe)	Sub-Bituminous & Lignite (Mtoe)	Total (Mtoe)	Share of Total(%)	R/P Ratio
N.America	134,220	134,434	268,654	26.3	286
L.Amercia	8,099	4,374	12,473	1.2	371
W.Europe	34,320	60,195	94,515	9.2	219
Middle East	-	-	-	-	-
Africa	65,317	224	65,541	6.4	357
Asia & Australasia	43,629	50,209	93,838	9.2	228
Socialist Countries	293,833	193,826	487,659	47.7	181
Total	579,418	443,262	1,022,680	100.0	218

The five largest coal producers in 1988 and their corresponding consumption levels are given in Table 7. Coal production was greater than consumption in all countries except China.

Table 7

Top Five Producers and Consumers of Coal+

(Mtoe)

Country	Production	Consumption
China	579.2	581.1
USA	524.3	479.8
USSR	391.9	310.1
Poland	142.4	102.0
India	121.9	102.0

+ BP Statistical Review.

The production* data in Mtoe** for 1983 and 1988 are presented in Table 8. The production increased in all blocs except Western Europe, where a decrease was noted. A part of this decrease can be attributed to the coal miners strike in the UK in 1983-84. Though the strike came to an end in early 1985, production did not regain its former levels even until 1988. In all other blocs, coal production registered an increase - 24 per cent in North America, 73 per cent in Latin America, 12 per cent in the Middle East, 28 per cent in Africa, and 17 per cent each in Asia and Australasia, and the socialist countries. This trend indicates higher production of coal in almost all countries which have coal reserves. In countries such as India and China, increasing quantities of coal are being used in thermal power plants.

Table 8

Coal Production

Country Bloc	1983 (Mtoe)	1988 (Mtoe)	Change from '87 to '88 (%)	Share of Total (%) (1988)
N.Amèrica	460.7	570.0	+5.2	23.4
L.Amercia	12.2	21.2	+14.0	0.9
W.Europe	204.2	186.8	+0.3	7.6
Middle East	0.6	0.7	-	+
Africa	88.9	100.0	+1.3	4.1
Asia & Australasia	184.1	235.9	-3.2	9.7
Socialist Countries	1134.8	1329.2	+3.0	54.3
Total	2085.5	2443.8	+2.7	100.0

+ less than 0.5

* Production refers to commercial solid fuels only, i.e., bituminous coal, anthracite (hard coal) and lignite brown (sub-bituminous) coal.

** The conversion factors 1.5×10^6t of coal and 3.0×10^6t of lignite for 1 Mtoe.

The coal consumption data is given in Table 9 for three years, namely 1978, 1983 and 1988. Between 1978 and 1988, the coal consumption in the world showed a steady increase, and the annual rate of increase was about 2.7 per cent.

Table 9

Coal Conusmption

Country Bloc	1978 (Mtoe)	1983 (Mtoe)	1988 (Mtoe)	Change from '87 to '88 (%)	Share of Total (%) (1988)
N.America	368.1	428.5	514.5	+4.4	21.2
L.Amercia	16.0	19.8	22.9	+0.7	1.0
W.Europe	233.5	248.6	263.5	+0.6	10.8
Middle East	-	1.4	2.5	+9.5	0.1
Africa	52.6	64.5	72.8	+7.7	3.0
Asia & Australasia	156.2	221.4	305.2	+8.3	12.6
Socialist Countries	1033.9	1055.0	1246.6	+2.8	15.3
Total	1860.3	2039.2	2428.0	+3.7	100

Among the country blocs, the net coal importing ones in 1988 were Western Europe, Middle East, Latin America, and Asia and Australasia. In contrast, the socialist countries were coal exporting countries. Within Asia, the prime importer was Japan, where consumption was greater than production by about 69 Mtoe.

1.1.3 Natural Gas

Estimation of natural gas reserves has always been subject to a great deal of criticism. Techniques are being perpetually refined to estimate reserves more accurately. The proven reserves at the end of 1988 were as given in Table 10.

Table 10

Natural Gas - Proven Reserves (at end-1988)

Country Bloc	Reserves (10^{12} cu.m.)	Share of Total(%)	R/P Ratio (years)
N.America	8.0	7.1	14.2
L.Amercia	6.7	6.1	70.0
W.Europe	5.7	5.0	33.6
Middle East	33.4	29.9	*
Africa	7.1	6.5	*
Asia & Australasia	6.8	6.0	56.6
Socialist Countries	44.2	39.4	51.7
Total	111.9	100.0	58.0

* over 100 years

Table 10 shows that most of the natural gas reserves are with the socialist countries followed by the Middle East. The two together accounted for about 70 per cent of the world reserves. Considering the current levels of the world's natural gas production, these reserves are expected to last approximately another 58 years. In the Middle East and Africa, these reserves are expected to last over 100 years.

The natural gas production trends for the decade 1978-1988 are shown in Table 11. Production figures exclude gas flared or recycled. Except North America, all other country blocs increased their production. The main contribution was from the socialist countries and Asia and Australasia. North America's production declined by about 10 per cent while Western Europe's production varied marginally over the period. Mexico's production increased between 1978-1982 but subsequently decreased drastically to 24.3 Mtoe in 1985. In 1988, production stood at 28.1 Mtoe indicating an increase of 28 per cent during the decade. From the table it can be seen that the major natural gas producers were the socialist countries and North America.

Table 11

Natural Gas Production*

Country Bloc	1978 (Mtoe)	1983 (Mtoe)	1988 (Mtoe)	Share of Total (%)	Change from '87 to '88 (%)
N.America	557.8	471.6	506.4	29.1	+2.8
L.Amercia	53.0	69.3	86.0	5.0	+11.5
W.Europe	151.5	147.1	150.4	8.6	-6.6
Middle East	42.4	36.5	65.3	3.7	+9.8
Africa	18.6	39.9	53.2	3.2	+4.4
Asia & Australasia	39.4	65.7	108.2	6.2	+5.4
Socialist Countries	391.5	548.9	768.8	44.2	+5.8
Total	1254.2	1379.0	1738.5	100.0	+4.1

* excludes gas flared or recycled.

Table 11 reveals that natural gas production increased over the decade. The rate of increase was about 2.5 times higher in the second half of the decade. The annual average rate of growth in production for the decade was 3.3 per cent. Within each country bloc the production increased by 96 per cent for the socialist countries, 175 per cent for Asia and Australasia, 186 per cent for Africa, 54 per cent for Middle East and 62 per cent for Latin America.

An outline of the consumption trends of natural gas (in Mtoe), is given in Table 12. For all major regions, the consumption grew over the ten-year period 1978-'88 except for North America where the consumption declined substantially over the period 1978-83, but grew marginally later on.

Table 12

Natural Gas Consumption

Country Bloc	1978 (Mtoe)	1983 (Mtoe)	1988 (Mtoe)	Share of Total (%)	Change from '87 to '88 (%)
N.America	548.0	482.0	506.6	31.0	+5.9
L.Amercia	42.3	63.1	79.0	4.8	+6.6
W.Europe	172.9	175.0	199.0	12.2	-3.6
Middle East	30.1	33.8	54.4	3.3	+6.0
Africa	11.1	25.2	30.2	1.9	+5.9
Asia & Australasia	38.6	60.5	97.7	6.0	+8.0
Socialist Countries	370.3	484.6	664.1	40.7	+5.7
Total	1213.3	1325.0	1631.0	100.0	+4.1

Table 12 shows consumption trends and reveals that during 1978-83 the natural gas consumption increased concomitantly with production. In the latter half of the decade, consumption grew at a slower rate than production (23 per cent in the second half as compared to 26 per cent for production). The overall annual average rate of growth for the decade was 3 per cent.

The main region importing natural gas in 1988 was Western Europe. North America also had some imports, though the bulk was for U.S.A., which was and which remained a net importer of natural gas. The exporting countries were the socialist countries with exports equal to 104.7 Mtoe. Africa had exports of 23 Mtoe followed by the Middle East, and Asia and Australasia each with 11 Mtoe.

1.1.4 Hydroelectricity

The trend in hydroelectric power consumption for the world is given in Table 13. The consumption figures refer to the amount of oil required to fuel an oil-fired plant to generate an equal amount of electricity from hydropower sources. In North America and Western Europe, the amount of electricity generated from hydel power either decreased or was constant in the ten-year period. This could be attributed to the attainment of a saturation level in the exploitation of hydel resources.

In the developing regions of the world, however, there was an expansion in the quantum of electricity consumed from hydroelectric sources. This could probably be indicative of a trend in most countries to invest heavily in large-scale hydroelectric projects in the initial phases of their development. However, the largest share of the total lies with North America, followed by the socialist bloc and Western Europe. The three regions put together accounted for over three-fourths of the total hydroelectricity consumed in the world.

Table 13

Hydroelectric Power Consumption

(Mtoe)

Country Bloc	1978	1983	1988	Change from 1987 to 1988 (%)	Share of Total (1988) (%)
N.America	135.7	154.2	143.0	-4.9	26.6
Latin Amercia	44.4	66.2	93.2	+3.2	17.4
Western Europe	102.1	107.5	107.7	+2.1	20.1
Middle East	2.5	2.5	2.6	-	0.5
Africa	10.4	14.8	18.9	+2.4	3.5
Asia & Australasia	40.6	51.3	59.5	+1.5	11.0
Socialist Countries	69.9	85.5	112.3	+3.6	20.9
Total	405.6	482.0	537.2	+0.5	100.0

1.1.5 Nuclear Energy

Belying all expectations and in the face of political, economic and environmental uncertainties about its future role, worldwide generation of nuclear energy has shown a strong growth throughout the 1970s and the 1980s with no sign of slackening in recent years. The nuclear energy consumption data given in Table 14 is in Mtoe for the three reference years. It is interesting to note that in most countries, there are no nuclear power plants.

Table 14

Nuclear Energy Consumption

Country Bloc	1978 (Mtoe)	1983 (Mtoe)	1988 (Mtoe)	Change from 1987 to 1988 (%)	Share of Total (1988) (%)
N.America	83.5	92.3	164.4	+15.4	37.5
- USA			144.8	+15.7	33.0
- Canada			19.6	+13.3	4.5
Latin Amercia	0.7	0.9	2.3	+3.9	0.5
West Europe	38.0	85.2	147.0	+5.9	33.4
- France			54.6	+1.5	12.4
- Sweden			14.8	+3.1	3.4
- U.K.			13.5	+15.3	3.1
- Germany			32.3	+11.4	7.3
- Others			31.8	+ 6.7	7.2
Middle East	-	-	-	-	-
Africa	-	-	1.9	-0.2	0.4
Asia & Australasia	14.8	36.9	65.9	-3.1	15.0
- Japan			43.4	-6.1	9.9
- Others			22.5	+3.2	5.1
Socialist Countries	14.6	32.7	57.3	+8.0	13.1
- USSR			42.5	+7.0	9.7
- Others			14.8	+11.3	3.4
Total	151.6	248.0			

Most of the capacity from this source of power generation lies in North America and Western Europe, which together accounted for over two-thirds of the total electricity generated from nuclear fuel source.

1.2 PRIMARY ENERGY CONSUMPTION

Considering total primary fuels, i.e. commercially traded fuels only, oil continued to dominate the world energy scene in 1988, accounting for around 38 per cent of the commercially traded fuels, followed by coal at 30 per cent, natural gas at 20 per cent, hydro at 7 per cent and nuclear energy at 5 per cent. This is highlighted in Table 15.

Table 15

World Commercial Primary Energy Sources - Mix (1988)

(Mtoe)

Country Bloc	Oil	Natural Gas	Coal	Nuclear Energy	Hydro-electricity	Total
N.America	863.9	506.6	514.5	164.4	143.0	2192.4
L.Amercia	228.1	79.0	22.9	2.3	93.2	425.5
W.Europe	594.1	199.0	263.5	147.0	107.7	1311.3
Middle East	135.4	54.4	2.5	-	2.6	194.9
Africa	86.2	30.2	72.8	1.9	18.9	210.0
Asia & Australasia	465.9	97.7	305.2	65.9	59.5	994.2
Socialist Countries	664.9	664.1	1246.6	57.3	112.3	2745.2
Total	3038.5	1631.0	2428.0	438.0	537.2	8073.5

Table 16 supplies data regarding primary energy consumption over a decade, giving details for each group of countries. The major consumer of energy in 1978 was North America (31.4 per cent), followed by Western Europe (18.6 per cent). The same relative positions were held in 1983 except that the difference between the consumption levels in North America and Western Europe decreased. By 1988, the largest consuming bloc comprised the socialist countries, which consumed about 34 per cent of the total as compared to North America's 27.2 per cent and Western Europe's 16.2 per cent.

Table 16

Total Primary Energy Consumption

Country Bloc	1978 (Mtoe)	1983 (Mtoe)	1988 (Mtoe)	Change from '87 to 88 (%)	Share of total(%) (1988)
N.America	2110.0	1930.0	2192.4	+4.5	27.1
L.Amercia	294.6	361.0	425.5	+3.0	5.3
W.Europe	1246.5	1188.0	1311.3	+1.0	16.3

Contd.

Table 16

Total Primary Energy Consumption (Contd.)

Country Bloc	1978 (Mtoe)	1983 (Mtoe)	1988 (Mtoe)	Change from '87 to '88 (%)	Share of total(%) (1988)
Middle East	118.1	155.7	194.9	+4.6	2.4
Africa	136.9	183.4	210.0	+4.1	2.6
Asia & Australasia	685.1	768.5	994.2	+7.6	12.3
Socialist Countries	530.2	552.9	2745.2	+3.0	34.0
Total	6715.2	6891.5	8073.5	+3.7	100.0

The preceding sections have described the consumption and production trends in primary energy the world over. Given the current situation where energy requirements far outstrip energy supply, and that conventional sources create environmental problems in addition to rapid depletion of energy resources, renewable energy technologies have begun to receive increased attention.

1.3 RENEWABLE ENERGY

Renewable energy technologies use energy sources capable of regenerating themselves, thereby implying an endless supply of energy. Renewable energy systems divert some of the natural energy flows present in the environment to serve useful human activities. Most of the renewable energy systems - based on energy sources such as biomass, water, wind and the sun - are currently designed to help rural residents overcome the problem of insufficient energy. Only a few rural communities are linked to national utility systems, because grid extensions to remote regions with dispersed population are both expensive and difficult. Traditional sources of energy, namely animal and fossil fuels, also have major drawbacks. It has been found that using animals as a source of labour lowers meat production. Petrol and diesel-powered engines require costly fuel and spare parts. Using wood and dung for cooking and heating places an additional burden on humans to collect fuel. Moreover, burning wood as fuel contributes to worldwide deforestation.

Because of these problems and the drain on foreign exchange due to a dependence on imported fuels, a movement has been launched to promote the use of locally

available renewable sources of energy - biomass, photovoltaics, wind, hydro, and the active and passive solar thermal - in applications where these are economically and technically feasible. Many renewable energy sources provide reliable, manageable, affordable and environmentally acceptable energy that is well suited to sustainable development and the conditions found in rural communities.

A brief state-of-the-art review of gasifiers, PV and solar thermal applications is presented below.

1.3.1 Gasifiers

Moving bed gasifiers with capacities of 50-500 kg wood/h producing low-calorific value gas are commercially available. The implementation rate in some developing countries is impressive especially for the smaller and cheaper units. Gasification of small and/or ash-rich particles is still a problem.

Fluidized bed gasifiers with capacities of several tons wood/h are commercially available but have been used only for heat production in North America. The process is in competition with direct combustion. The process is capable of using various types of biomass, but economically feasible down-scaling is still a problem.

About ten medium Joule-gas demonstration plants at capacitites of 1060 t/d are operating or under construction in the European Community, USA., Sweden, and Brazil. Both oxygen and steam gasification are being tested in various reactors and with several methods of heat supply (in steam gasification). Nearly all processes are intended for methanol production. The main development areas remaining are to achieve a favourable gas composition (low in hydrocarbons) and pressurized up to about 15 bar (particularly in double fluidized bed systems). The main problem in large-scale implementation is economically viable down-scaling of the process to capacities of 100-500 t wood/h. Competition from methanol (from coal) and natural gas (also from remote areas) will probably be strong. Preliminary relative cost estimates for the different processes agree to within 20 per cent which is not significant in light of the uncertainties in both capital and operating costs.

Catalytic gasification has received increasing attention over the past five years, particularly in USA. The aim is to produce specific gas compositions for downstream synthesis processes (methanol, methane or ammonia) at low temperatures, particularly with steam gasification. The main problems are stability of catalyst and deactivation.

1.3.2 Photovoltaic Technology

The transition from the space-borne application of solar cells to their terrestrial use has been quite remarkable in the wake of broad based efforts initiated in 1974. This has led to the development of more energy-efficient PV devices, poised to become quite cost effective in a few years from now. Some of the most recent achievements in case of PV technology can be grouped under two heads, namely (a) Laboratory R&D, and(b) Commercial applications.

The development of single-crystal silicon solar cells with an efficiency of 24 per cent goes to the credit of Dr. Martin Green of the University of New South Wales. This value is the highest for todays' dominant cell material, namely silicon.

PV researchers all over the world believe that amorphous silicon cells have a long and promising future. The thin film division of Solarex has achieved a record 9 per cent efficiency for large area, triple junction amorphous silicon solar cells. The high performance, module is composed of three cells, stacked one on top of the other. The top cell, made of amorphous silicon carbide, has the greatest sensitivity to the blue light. The middle cell (amorphous silicon) converts light in the green-yellow part of the spectrum, and the bottom cell (amorphous Si-Ge alloy) captures the light in the infrared spectrum.

The solar cell concentrator technology research is progressing at the Sandia National Laboratories. Efficiencies of 26 per cent using silicon as the base material are being claimed.

An unbelievable conversion efficiency of 38 per cent has been attained on a laboratory scale for GaAs/GaSb tandem cell structure. PV cells made from III-V semiconductors offer the highest efficiencies based on the existing technology.

The pilot line facility at Palo Alto produces batches of GaAs solar cells with efficiencies exceeding 20 per cent (one sun, AM0)*

During the initial tests carried under simulated space conditions (AM0), the three-layer cell of AlGaAS/GaAS/InGaAS shows an efficiency of about 25 per cent. The greatest applicability of this technology is in solar concentrators.

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* One sun = 1000 W/m^2
AM0 = air mass zero

The production of photovoltaic modules on a global level increased by 22 per cent from its 1988 level to 42.75 MW in 1989. There exists a substantial demand for power modules based on the crystalline silicon cell technology. Globally, amorphous silicon modules registered a small increase in production. The information given in Table 17 describes the global PV production scene in 1988 and 1989.

Table 17

Worldwide PV Module Manufacturing Activity (MW/P)

	1989		1988	
	Output (MW/P)	World Market Share (%)	Output (MW/P)	World Market Share (%)
United States	15.5	36.25	12.4	35
other materials	(11.7)	(27.3)	(8.8)	(25)
a-Si modules+	(3.8)	(8.8)	(3.6)	(10)
Japan	12.75	29.8	11.75	33.57
other materials	(3.5)	(8.0)	(3.25)	(9.5)
a-Si modules	(9.25)	(21.6)	(8.5)	(24)
Europe	8.75	20.4	6.4	18
other materials	(6.50)	(15)	(4.9)	(14)
a-Si modules	(2.25)	(5)	(1.5)	(4)
R.O.W*	5.75	13.5	4.5	12.8
other materials	(5)	(11.6)	(4.0)	(11.4)
a-Si modules	(0.75)	(0.01)	(0.5)	(1.4)
	42.75	100	35	100

* Rest of the world

\+ amorphous silicon modules

1.3.3 Solar-Thermal Appliances

At most temperature ranges, energy from the sun can be transformed to thermal energy to meet the requirements of various units, households, etc. This is referred to as the solar-thermal aplication.

The latest advancement in this field is the installation of solar-thermal power plants based on point focussing and line focussing collectors, coupled with steam turbines. Efforts to determine the cause of the gradual deterioration in the reflectance of the mirror material

on exposure to the industrial environment is being persued. In addition a study of the ultraviolet component in the solar radiation is also underway.

Sustained and broadbased initiatives are being taken to store thermal energy in view of the intermittent and diffuse nature of solar energy. Materials and methods for such an application are also being identified.

1.4 ENERGY POLICIES

Japan and a few member countries of the European Economic Community (EEC) have taken effective measures to conserve energy* and curb the use of petroleum products. They have shown that through comprehensive policy measures, it is possible to delink energy consumption and economic growth. Here are some examples of energy conservation policies of Japan and EEC.

1.4.1 Japan

The overall responsibility for policy formulation lies with the Ministry of International Trade and Industry (MITI). Four categories of energy policies adopted were related to (a) measures pertaining to energy conservation, (b) measures providing incentives energy conservation, (c) research and development, and (d) publicity.

A law pertaining to 'Rationalization in the Use of Energy' was promulgated in October 1979, and as a consequence rigorous energy conservation measures were implemented.

Under the measures pertaining to energy conservation, authorities can fix and enforce standards for rationalization of energy use in factories, e.g. recovery of waste heat of combustion and conversion of heat into power. Energy use in buildings should be rationalized by proper insulation of walls and by using energy effectively. Incentives that are provided for energy conservation cover financial benefits, commendations and free/subsidized energy audits. To improve the energy infrastructure, a system of tax incentives to promote investments, called an energy-based investment promotion taxation system, exists. A 30 per cent depreciation in the first year is permitted on energy conservation equipment. Reduction of corporate tax in the range of 7-20 per cent on investment is allowed. In addition, a special loan system exists, where lower interest rates are charged.

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* Energy conservation is considered to be a supply option and sometimes referred to as the 'fifth fuel'

Another scheme aims at promoting energy conservation by giving prizes to individuals or factories who contribute to energy efficiency improvements. Energy audits are conducted free of cost for small- and medium-sized companies, while larger companies are allowed to establish their own energy conservation programmes.

In 1978, the MITI launched the "Moonlight Project" which provided the framework for integrated research and development on energy conservation.

Awareness of the need for energy conservation is vital to the success of energy conservation policies. Therefore, widespread information dissemination of the same is undertaken by MITI.

The energy conservation policies of Japan have succeeded largely due to increased awareness and the willingness of the industrial, commercial, transportation and residential sectors to comply with the law.

1.4.2 European Economic Community (EEC)

EEC's policy initiatives were aimed at a more rational utilization of energy to improve energy use efficiency by reducing losses and gradually eliminating non-essential consumption.

The policies after the second oil shock were aimed at

a) reducing the community's share of oil in total energy consumption from around 56 per cent to 40 per cent;

b) increasing the share of coal and nuclear energy for electricity generation to 70-75 per cent; and

c) reducing the ratio between energy demand growth and economic growth to less than 0.7 from 0.94.

The effects of these policies were

a) improved energy efficiency

b) a fourfold increase in nuclear power generation

c) increased use of coal and other solid fuels in power stations

d) increased consumption and increased net imports of natural gas

e) the coming on-stream of oil from the North Sea.

The sectoral objectives of the nineties are as follows:

a) to continue improvements in energy efficiency to achieve 20 per cent reduction in energy consumption;

b) to maintain net oil imports at less than one-third of the total energy consumption;

c) to maintain and, if possible, to increase the market share of natural gas and solid fuels;

d) to reduce the use of oil and gas in electric power generation to about 10 per cent;

e) to ensure that about 40 per cent of electricity output is from nuclear energy; and

f) to increase efforts to develop and commercialize new and renewable sources of energy, with a view to trebling their contribution to total energy by the turn of the century.

EEC has achieved significant progress in increasing its energy supply, limiting its energy demand growth and finding suitable alternatives to oil. These results have been possible due to timely action in implementing certain goal-oriented policies.

Suggested Projects

1. Analyse the events which have affected the international price of crude in the past. Discuss the effect on production and consumption due to changes in oil prices, and its impact on imports and exports.

2. Project the trends in oil prices in the future. Analyse its impact on production, and on various economies of the world.

3. Compare the different energy alternatives available in terms of their efficiency of usage, relative price, regional availability and environmental impact.

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INDIA'S ENERGY SCENE

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INDIA'S ENERGY SCENE

A high rate of growth in consumption, increasing supply of various energy sources, though not in pace with demand, and growing reliance on non-renewable sources of energy (especially oil) characterize India's energy scene.

While increased quantities of coal are being consumed by thermal power stations, the coal consumption has been more or less stable in the industrial sector and in the domestic and transportation sectors it has shown a decrease. The increase in oil consumption is mainly in the transportation and industrial sectors. Electricity consumption in the domestic/commercial and agricultural sectors has shown rapid growth while in the industrial sector, the growth rate has been moderate. On the one hand, large investments are being poured into the energy supply sector (the 7th Plan allocation for the energy sector was around 31 per cent of the total Plan allocation) to increase energy supply while on the other, energy demand has been growing more rapidly. Contribution from renewable energy sources (excluding traditional fuels) still remains a small fraction of the total energy consumed in the country. However, the potential remains high, and renewable energy can be expected to make a large impact on our energy scene in the future.

Common sense demands that a country which is affected by serious energy shortages must, even as it increases the supply of energy by all means available to it, also ensure that it makes the most efficient use of whatever energy it consumes.

However, energy conservation has not so far played a significant role in reducing our energy requirements. The potential for conservation remains high in industry, transport, agriculture and domestic sectors, in that order. With proper policies and education, energy conservation could be expected to have a major impact on our energy scene in the future. Energy conservation no longer optional; it is a necessity.

Over the years, the prevailing school of thought has been that increases in energy intensity and consumption were an indication of economic growth and development of an economy. In recent years, in the face of an energy crisis, there has been an attempt in the developed countries at delinking increases in energy use from economic growth. This might not hold true for developing economies like India where an increase in energy consumption is forecast, though the rate of growth of energy consumption could be slower than anticipated.

Though the Indian economy has consistently shown an upward trend in the overall commercial energy consumption intensity since the mid-eighties, a downward trend was observed in 1974-75 and 1980-81. The upward trend in commercial energy consumption intensity could be a result of the following:

a) An increased mechanization of Indian agriculture, which is more capital intensive, leading to adoption of energy intensive methods of cultivation. This trend is particularly noticeable after the Green Revolution of the late '60s.

b) An increase in the energy consumption levels in industry. The initial rush for capital intensive industries and increasing capacities being created in these energy intensive sectors have led to an increase in the energy intensity of the industrial sector.

c) A greater increase in private transportation modes as compared to public modes has led to an increase in the overall energy intensity.

d) An increase in the quantum of commercial energy used in the domestic sector.

In this chapter an analysis of the trends in energy production and energy consumption in India is given.

Table 1 summarizes the developments in the energy sector over the decade 1978-79 to 1987-88. Estimated figures for 1988-89 from the Economic Survey 1989-90 are also included. It can be seen that coal consumption increased by 70 per cent over the decade, at an annual average rate of 6.5 per cent. Consumption increased by around 15 Mt between the period 1987-88 to 1988-89. Lignite consumption also grew during this period, at an annual average rate of 13.4 per cent. Consumption levels increased by over 2 Mt in a single year between 1987-88 and 1988-89.

Table 1

National Commercial Energy Consumption (1978-79 to 1988-89)

Year	Coal (Mt)	Lignite (Mt)	Total Solid Fuels (Mt)	Natural gas(1) (M.cu.m)	Crude Petroleum ('000t)	Pet. Products ('000t)	Hydel Power (MkWh)
1978-79	101.97	3.27	105.24	2811	11633	25671	47138
1983-84	138.22	7.30	145.52	5961	26020	34793	49867
1987-88	179.75	10.15	189.9	11467	30357	47277	47400
1988-89	194.6	12.4	207.0	13220	32040	49760	47800

Pet. - Petroleum.

(1) Represents the total natural gas extracted from on- and off-shore wells.

Natural gas (NG) extraction also increased over this period from 2811 to 13220 M, implying an annual average rate of growth of 16.9 per cent. Crude petroleum consumption grew rapidly at a rate of 17.5 per cent during the period from 1978-79 to 1983-84; the aggregated rate of growth for the period 1978-79 to 1983-84 being 11.2 per cent per annum.

Hydel power generation decreased marginally by about 4 per cent over the period 1983-84 to 1987-88 and then increased between 1987-88/1988-89.

Pricing. Since energy is a vital input in the economy, the Indian government decided to administer the prices of various fuels, in the interest of certain social and egalitarian objectives. Hence, energy prices do not truly reflect the costs. The benefits of a cross subsidy (between petrol and kerosene) have not been reaped by the sections of society they were intended for. An example is the subsidy provided on kerosene and diesel, ostensibly because they are consumed by the poorer sections of society. The benefits of this subsidy have been reaped by the richer sections of society and by the transport industry. The low prices have increased demand unproportionately and skewed the demand for petroleum products heavily towards the middle distillates.

2.1 COAL

Coal is the most abundant commercial energy source in India. Coal reserves are assessed on a continuous basis by the Geological Survey of India, through regional mapping and exploratory drilling. Proven coal reserves as on 1989 stood at approximately 52,000 Mt. Of the total reserves, prime coking coal reserves accounted for about 8 per cent; medium, semi-coking coal about 18 per cent and non-coking coal about 74 per cent. Lignite deposits occur primarily at Neyveli in Tamil Nadu and in a few places in Gujarat and Rajasthan. Of the 2600 Mt in the total proven reserves category, about 2100 Mt, i.e., 81 per cent, occur at Neyveli.

The integrated development programme for the coal industry has resulted in a programme of an optimal selection of new technologies, standardization of equipment and infrastructural development, in addition to a reorganization of the existing mines. Better equipment and a planned exploitation of the reserves have resulted in increased output per man-shift. This restructuring has probably been the prime cause of increased output since the late seventies.

The basic property of coal as a fuel is its combustion potential or its calorific content. Other physical and

chemical characteristics, particularly the ash and moisture content, are also important properties. While the sulphur content of Indian coals is usually low, the ash content is high. Ash comprises residual non-combustible matter from silt, clay, silica, etc. The heating value of coal decreases with an increase in ash because some heat is used as the ash melts. The reduction in heating value might become a significant fraction of the total gross calorific value of the coal if ash content is high. Hence, for Indian coals, a useful heating value is specified and the difference between the gross calorific value and useful heating value increases with an increase in the ash content.

The grading of coking coals is basically related to the percentage ash content whilst that of non-coking coal is based on the useful heat value. This difference in grading criteria arises since the moisture content of coking coals is low.

The gradewise production of coal reveals that the majority of India's production (78 per cent) is in the non-coking coal category. This production is distributed primarily over grades B to E. Washery Grade IV is the primary type of coking coal mined in India.

Over the past decade, the average calorific value of both coking and non-coking coals has declined. This could be attributed to increased mechanization in opencast mining methods, which leads to a significant proportion of dirt, boulders, etc. getting mixed with coal during extraction.

The demand for coal in 1988-89 was estimated to be 202 Mt. With the possibility of drawing from pit-head stocks and the requirement of steel plants being met by imports, production target was fixed at 196.3 Mt. The actual production, while registering a growth rate of 8.3 per cent over the previous year, fell short of the target by 1.7 Mt. This could be attributed to labour problems, strikes and absenteeism in some of the mines. Total dispatches of coal were 7.4 per cent higher than the previous year's 170.75 Mt. Despite larger dispatches there was a higher build-up of pit-head stocks, which could be caused by a mismatch between production and transportation.

The gap between demand and domestic production for 1989-90 is estimated at 12.5 Mt, of which about 8 Mt will come from pit-head stocks and 4.5 Mt will be the imported coking coal required for the steel industry.

2.2 OIL

The total estimated oil and oil-equivalent of gas resources of India are about 17 billion tonnes. Compared to the large total reserves, the reserves in the proven and (balance) recoverable category are rather small. As of January 1987, only 3.3 billion tonnes of in-place oil and gas reserves had been established and as of January 1988, only 688 Mt of crude oil was in the proven and recoverable category. Bombay High accounts for about 58 per cent of the crude oil reserves. Given the production of crude as 32 Mt, at the current levels of production, crude reserves could be expected to last for about 20 years (this is known as Reserves/Production ratio).

Table 2 traces the developments in India's oil industry in the 1980s.

Table 2

Commodity Balance of Crude and Petroleum Products (Mt)

	1980-81	1983-84	1988-89
I. CRUDE			
1. Refinery throughput	25.8	35.3	48.8
2. Domestic production	10.5	26.0	32.0
(a) Onshore	5.5	8.6	10.9
(b) Offshore	5.0	17.4	21.1
3. Imports	16.2	16.0	17.8
4. Exports	-	5.5	-
5. Net imports (imports - exports)	16.2	10.5	17.8
II. PRODUCTS			
1. Domestic consumption* of which	30.9	35.8	49.8
a. Naphtha	2.3	2.8	3.3
b. Kerosene	4.2	5.5	7.7
c. High Speed Diesel (HSD) Oil	10.3	12.6	18.7
d. Fuel oils	7.5	7.6	8.4
e. Others	6.6	7.3	11.7

contd.

Table 2

Commodity Balance of Crude and Petroleum Products (Mt) (Contd.)

	1980-81	1983-84	1988-89
2. Domestic production of which	24.1	32.9	46.4
a. Naphtha	2.1	3.6	5.4
b. Kerosene	2.4	3.5	5.2
c. HSD Oil	7.4	10.9	16.7
d. Fuel oils	6.1	8.0	16.7
e. Others	6.1	6.9	2.4
3. Imports	7.3	4.3	6.3
4. Exports**	-	1.5	2.3
5. Net Imports	7.3	2.8	4.0

* Excluding refinery fuel consumption
** Excluding supplies of Petroleum Oil & Lubricants (POL) products to Nepal
'-' Negligible

Domestic production of crude grew rapidly in the early eighties, at an annual average rate of growth of 35.3 per cent. This, however, slowed down drastically in the latter half of the decade, growing only at a rate of 4.2 per cent per annum. The compound rate of growth over this period was a substantial 14.9 per cent. The share of offshore production increased from 48 per cent of the total production in 1980-81 to 56 per cent in 1988-89. Imports also increased, though only marginally, from around 16.2 to 17.8 Mt over this period. This increase in petroleum and petroleum products imports has occurred despite the rapid increase in domestic production over this period. Although the net import bill since 1980/81 is reported to be substantially less due to a rapid increase in indegenous crude production (with self-sufficiency increasing up to 60 per cent in 1983/84), and low oil prices in the international market, net imports have continued to rise steadily till date, and with crude production having more or less stabilized since 1984-85, the possibility of a further decrease in the import bill appears improbable.

Domestic consumption of naphtha increased by 1 Mt between 1980-81 and 1988-89 implying a growth rate of 4.6 per cent per annum. Production increased an an annual average rate

of 12.5 per annum over the same period. Kerosene consumption increased at 7.9 per cent per annum, while production increased at an annual average rate of 10.7 per cent. There was, however, a net deficit of 2.3 Mt of kerosene, which had to be compensated for by imports. The consumption of high speed diesel oil (HSDO) increased by 82 per cent over this period and outstripped production by 2 Mt. Moreover, the production of fuel oils was less than consumption in the first two years of reference, but marginally exceeded the consumption in 1988-89 by 0.5 Mt.

The artificially high demand for kerosene and diesel accounted for the bulk of the petroleum product imports. The high level of demand arises from the fact that both products are highly subsidized and the price differential between the two is not accounted to change substantially due to a fear of adulteration.

2.3 NATURAL GAS

As of January 1988, the proven and recoverable reserves of gas were 579 billion m^3, of which Bombay High accounted for about 71 per cent. Given the natural gas production level as 13.22 billion m^3 in 1988-89, at the current levels of production, the reserves are expected to last about 44 years (on the basis of the R/P ratio).

Around 28-30 per cent of the gas produced is flared and drastic reductions in the amount flared have not been possible, primarily due to delays in commissioning downstream gas utilization facilities. The flexibility associated with reducing the production of associated gas is limited because this can be achieved only if oil production is also limited. Gas production can only be limited to fields which have free gas reserves. The production profile from such fields may be adjusted to the extent that gas can be utilized purposefully downstream.

If new hydrocarbon discoveries would have associated gas reserves, it becomes necessary to develop a suitable gas pipeline system and other downstream facilities in a coordinated manner. To this effect, the ONGC's plan of a national gas grid, to be implemented in phases to provide flexibility in the utilization of natural gas and to reduce regional energy imbalances, is a viable solution.

In order to utilize this vast, clean source of energy, integrated resource planning, implying a high degree of coordination and synchronization, is required. The long-term policy on gas utilization in India should aim at gas substituting the middle distillates, the consumption of which is currently very high. Hence, the relative importance of gas in the energy mix in the next few years is expected to increase.

2.4 HYDROELECTRICITY

As regards the hydel-thermal mix in power generation in the country, the share of electricity from thermal energy has been steadily increasing. The thermal power generation capacity at present constitutes over 70 per cent of the total installed capacity and contributes about 74 per cent of the total power generated. However, in terms of gross capacity, hydel power increased from 11.8 GW in 1980-81 to 17.8 GW in 1988-89, implying a 51 per cent increase, at an annual average growth rate of 5.3 per cent.

Hence, while hydel capacity has increased, its share in electricity generation relative to the growth of total capacity has decreased. While it is not easy to determine an optimal or desirable hydel-thermal mix, as it is a function of the system load curve, etc., it is felt that a concerted effort must be made to increase the share of hydropower capacity in the future. One of the options available is the installation of mini- and micro-hydel stations, an alternative which has not been adequately exploited in India.

One of the most important reasons for the decline in the share of hydro capacity is that the gestation period is considerably longer than that of a thermal power plant. Whilst there have been time overruns in the commissioning of both hydro and thermal projects in the past, the site-specific nature of hydel plants implies non-standard procedures being adopted and hence longer delays.

The hydel-thermal generation mix has changed substantially, especially since 1970-71: starting from a 1:1 ratio in the 1950s, it changed to 1:2.4 in 1986-87 and then to 1:2.7 in 1988-89.

Another reason for the decline in hydel power generation could be the gradual reduction in the average utilization rate of hydro projects. This perhaps suggests that generally, hydro plants are increasingly being used at an all India level mainly for peaking purposes. However, regional variations could exist.

In absolute terms, hydel generation has increased over the years at an annual average rate of growth of 8.6 per cent since 1950. In the 1980s, the rate of growth decreased to 2.8 per cent per annum. Hydel generation of 57.8 billion kWh in 1988-89 signifies an improvement of 29 per cent over the 1980-81 figure and was close to its target level. The exception was in 1987-88. The shortfall in hydel power generation in that year was primarily due to the failure of the monsoon.

The annual utilization of hydel power plants has decreased from 45.2 per cent in 1970-71 to 37.5 per cent in 1988-89. The utilization rate was at the lowest in 1987-88, i.e., 31.4 per cent.

Given the long gestation periods of 120 months (average) for hydel plants, the government is now assessing the feasibility of micro/mini/small hydro stations as an option to meet the demands of a few small areas. These plants require less investment and have shorter gestation periods. However, resource use optimization and improved project management techniques are a prerequisite if hydro-electric potential is to be exploited at a higher level.

2.5 NUCLEAR ENERGY

India's nuclear programme started in 1970/71, when nuclear energy was harnessed to augment electricity generation in the country. In 1970/71, the installed capacity of nuclear plants was 420 MW and the gross generation stood at 2417.38 GWh, accounting for 2.9 per cent of the capacity and 4.3 per cent of the gross generation. In 1988-89, the share of capacity decreased marginally to 2.2 per cent though, in absolute terms the capacity increased to 1.3 GW. The share of gross generation, too, dropped to 2.6 per cent, despite an increase in generation to 5800.0 GWh. This shows that while in absolute terms the contribution of nuclear energy to the total electricity generated increased steadily over the years at an annual average rate of 5 per cent, its share in total generation decreased, as gross generation grew at a faster rate of 7.9 per cent per annum over the corresponding period.

Three nuclear power stations* are in commercial operation: Tarapur (Maharashtra), Rowatbhata (Rajasthan) and Kalpakkam (Tamil Nadu). All are based on heavy water reactor technology. However, the functioning of all three nuclear power stations has been beset with problems and long periods of shutdown have been reported. Three new nuclear power stations are under construction at Narora (U.P.), Kakrapar (Gujarat) and Kaiga (Karnataka). In addition, two new units are being added to the Rajasthan station. All the new capacity and expansion activities are expected to be completed by 1995/96. The main slippages in the construction schedule have been due to problems in land acquisition, delays in finalizing designs tailored to suit the seismic requirements of the region, delays in fabricating certain critical equipment and non-availability of certain construction materials.

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* At the time of writing, one unit of the Narora Nuclear Power Station had been commissioned, implying an increase of 235 MW of capacity. The unit is still not under commercial operation.

Given the natural uranium resources and thorium oxide reserves in the country, the Working Group on Energy Policy suggested that India could support a nuclear power programme of about 8000 MW. There is, therefore, considerable scope for expanding the country's nuclear programme from the current levels and this potential can be increased severalfold if the fast-breeder reactor technology is successfully experimented and introduced.

2.6 RENEWABLE ENERGY[1]

Given the current scenario of increasing consumption of commercial fuels and their increasing prices, a rising import bill and adverse environmental impact, it is necessary to augment current supply with energy from renewable sources. To achieve this end, the Government set up the Department of Non-conventional Energy Sources (DNES) in 1984. In addition, consistent efforts have been made at improving the R&D activities in the field. While large scale dissemination of some relatively mature technologies such as biogas plants, improved chulhas, solar cookers and solar water heating systems has already been done, other technologies are still being demonstrated or tested in pilot plants in the field. Often, the Government has had to provide incentives such as direct subsidies or soft loans and sales tax exemptions to promote these renewable energy technologies.

2.6.1 Solar Thermal Systems

Typically, under normal clear sky conditions, the energy received per sq. km is in the range of 4-7 kWh daily and the total solar radiation received on Indian soil is about 6×10^{15} kWh per annum. While the entire incident radiation cannot possibly be harnessed, with the right technologies a substantial quantum can be effectively utilized.

While the technical viability of solar hot water technology and solar cookers has been established, new devices such as solar timber kilns and air heaters have recently been included in the extension programme, after successful field trials.

Largely due to the subsidies provided by DNES, and supplemented with those provided by state governments, the market for solar thermal devices grew rapidly in 1984-85. This trend has more or less persisted over the later years, as is indicated in Table 3.

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* The estimates of animal power are somewhat vague. In 1985-86, it was estimated that 15 million animal carts were in operation. However, it is not known as to how many of these were single animal driven.

Table 3

Number of Solar Thermal Devices Installed

	Cumulative as of 31 March 1988	Cumulative as of 31 January 1989
Solar water heating systems	1563	2150
Solar air heaters/ crop dryers	33	34
Solar timber kilns	36	39
Solar stills	6901	7280
Domestic solar water heaters	2043	3025

The above table however does not list the most popular solar thermal device - the solar cooker. Over 92,000 cookers have been disseminated to date, a fact attributable mainly to the large subsidy provided.

2.6.2 Solar Photovoltaics

Photovoltaic (PV) systems are modular in nature and can be used to meet electrical energy requirements for a variety of applications. Solar PV systems are relatively easy to install and maintain and have a comparatively longer life. They are, therefore, suited for use in remote and isolated areas and in villages where energy requirements are minimal and which cannot easily be serviced by conventional electricity grids.

Table 4 traces the progress of the PV demonstration programme in India.

Table 4

Number of Solar Photovoltaics Installed in India

	No. installed up to 29.2.88	1988-89 Target	1988-89 No. installed up to 31.12.88
Water pumping systems	852	100	102
Street lighting systems	9200	3000	3179
Domestic lighting systems	550	500	405
Community lighting and TV systems	243	100	67
Battery charging units	631	not specified	
Solar PV plants (small) (kWe)	115	100	120

Table 4 reveals that while in some cases the achievement exceeded the target, in the case of domestic lighting systems, and community lighting and TV systems, the actuals fell short of their targets.

Solar energy offers tremendous potential for the growing energy needs of the country. Imaginative planning and utilization of this source in the form of power batteries for automobiles or agricultural pumps need to be expedited so that the use of hydrocarbons by these sectors can be reduced.

2.6.3 Wind Energy Systems

During the initial years of the Seventh Five Year Plan period, the wind energy programme expanded rapidly. This rate of growth, however, could not be sustained in subsequent years. The annual rate of increase has risen to 21 per cent in 1988-89. Table 5 gives an indication of the same.

Table 5

Cumulative Number of Windmills Installed

	as on 28.2.85	as on 31.3.86	as on 31.3.87	as on 31.1.88	as on 31.3.89
All India Total	814	1352	1717	1946	2362

The performance of wind electric generation systems has been encouraging and so far the programme has, by and large, been successful. However, despite preventive measures, certain problems still remain. For example, in the case of a weak grid, the entire load falls on the wind electricity generator (WEG), reducing the life of the equipment. Conversely, if a wind farm generates electricity beyond the tolerance range and frequency of the grid, the supply voltage from the grid is affected. Alternatively, if these systems are used as stand-alone systems, the above problems can be overcome, but mechanical faults or faults in the inverter system could still occur. However, as stand-alone systems, they could effectively cater to the needs of remote areas (with limited load) and in addition, reduce T&D lossses and the investments required in the distribution network.

2.6.4 Biomass

While the theoretical potential of biomass in India is immense, there are many practical difficulties in producing biomass on a large scale. Most of the land suitable for biomass production is already being used to produce food, feed, fodder or timber to meet the burgeoning needs of a growing population.

There are different methods of converting biomass to energy. One is the simple, direct burning of solid wood or other plant material. The second is the conversion of biomass into a gas, or a liquid, e.g., methanol. The third method is a biological process in which bacteria break down organic waste into methane gas. Biogas can be harnessed to meet most of the energy requirements of rural households.

The importance of biomass in domestic consumption cannot be overemphasized. As much as 93 per cent of the fuel needs of rural households are met by non-commercial energy sources. The corresponding figure for urban households is 61 per cent.

According to the IT Power report, the fuel mix in terms of per cent of useful heat from biomass sources in urban and rural households stood as follows*

	Rural	Urban
Firewood & other solid wastes	70.4	55.8
Dung	27.4	8.1

* These estimates vary marginally from the Advisory Board on Energy (ABE) estimates of 75 and 20 per cent for the rural areas and 33 and 4 per cent for the urban dwellers. The discrepancy could arise due to conversion factors as the ABE has its figures in kg coal replacement (kgcr) while the IT Power report has its figures in kg oil equivalent (kgoe).

Based on this fuel mix and the efficiency of utilization, the ABE arrived at an estimate for the total energy requirements for cooking, lighting and heating in 2004/05, assuming a population of 1003 million. Table 6 gives the ABE's aggregate biomass estimates.

Table 6

Biomass Requirements in 2004/05

Fuel Type	Unit	Requirement
Fuelwood	(10^6t)	300
Veg./Agriculture Residue	(10^6t)	90
Animal Dung	(10^6t)	169
Gobar Gas	(10^6 m^3)	169

The NCAER survey on domestic fuels includes a detailed breakdown of annual per capita gross energy consumption in 1978-79 for both urban and rural households. These estimates are presented in Table 7.

Table 7

Domestic Sector:

Annual Per Capita Gross Energy Consumption

(1978-79)

Fuel Type	Unit	Cooking		Water Heating		Space Heating		Total	
		Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Fuelwood	kg	77.49	38.53	5.13	1.41	0.20	0.13	82.82	40.07
	kgoe	35.67	17.74	2.36	0.65	0.09	0.06	38.12	18.44
Dung-cake	kg	32.90	128.33	2.57	4.31	0.27	0.38	35.69	133.02
	kgoe	6.87	26.60	0.53	0.89	0.05	0.08	7.40	27.57
Agricultural wastes	kg	38.79	168.66	2.58	7.20	0.13	0.95	41.49	176.81
	kgoe	11.64	50.60	0.77	2.61	0.039	0.29	12.45	53.04

Table 7 reveals that while in absolute terms the consumption of various biomass fuels is high, in terms of useful heat value, i.e., kgoe, it is fairly low. This is largely due to the low average efficiency of utilization. This can be seen by the fact that the average efficiency utilization of fuelwood, dung-cake and wastes is 14, 8 and 12 per cent respectively as compared to LPG's 60 per cent (IT Power report).

2.6.5 Fuelwood

India has a total forest area of about 75 million ha which forms about 19,5 per cent of the total geographical area. The total availability of fuelwood in terms of logs, according to the Report of the Fuelwood Committee (1982), was about 50 Mt, which the Committee estimated would only meet less than half of the actual requirements.

The NCAER domestic fuel survey indicated that fuelwood in terms of logs and twigs met 47 per cent of the useful energy requirement in 1978-79, i.e., 94.49 Mt of wood. The dependence of rural households on this source is over 70 per cent as is indicated in Table 7. Urban centres mostly consume logs.

On the basis of various normative estimates, the ABE proposed that the daily per capita useful energy consumption should be 620 kcal. Assuming that the fuel mix of 1978-79 remained unaltered, i.e., 56 per cent of the useful energy requirement being supplied by fuelwood and with a conversion efficiency of 8 per cent (ABE), the present 'desired' demand would cross 230 Mt.

Currently the overall deficit in the country is 170 million m^3 with production being 12.45 million m^3. If current consumption trends are to continue in the future, the fuelwood supply situation can be expected to worsen further. Improvement, if any, is possible only in the long-term, provided steps are taken now. To this end, the Government of India has entrusted the National Wastelands Development Board with the task of afforesting 5 Mha annually. A specific target of 2.5 Mha of fuelwood plantations is also envisaged. Any new scheme must be evaluated against the fact that over 94 per cent of total consumed twigs and 54 per cent of consumed fuelwood in rural India are 'collected' at zero private cost.

2.6.6 Crop Residues

Estimation of the availability of crop residues is very complex because of the nature of the competitive demand for it. As India has one of the largest livestock populations in the world, the total fodder requirement is immense. No data is available for the fractions used as fodder or for heating needs. A number of studies have been carried out in this field/area. While the estimates of the availability gap have varied, all studies do conclude that in future the availability of fodder will fall short of requirement. Annual dry fodder requirements, based on normative feeding requirements of the National Commission on Agriculture, were estimated at approximately 495 Mt in 1977. In states such as Rajasthan and Gujarat, the fodder shortage is far more serious than the fuelwood shortage.

2.6.7 Animal Waste and Biogas

Animal waste in the form of dung met approximately 16 per cent of useful energy requirement in India in 1979. The dependence of the rural population on this fuel was as much as 5 times that of the urban residents. The rural consumption of dung-cakes was 66.7 Mt, i.e., 21.1 per cent of energy requirements, implying that about 333 Mt of wet dung was used. Given a large livestock population, the potential for supply of dung is immense. However, there are serious constraints to the successful and efficient utilization of dung for biogas. Though biogas is cheaper as compared to commercial fuels such as LPG, it is unable to compete in financial terms with dung-cakes, crop residues and fuelwood, which are obtained at zero private cost; nor has biogas technology developed to the level of sophistication of other competing technologies. In addition, the diffused nature of livestock ownership, nature of feeding practices and widespread free grazing are responsible for a low dung collection efficiency. Table 8 sums up the above facts in terms of numbers.

Table 8

Dung Consumption

Total dung produced ('000 t)	Total dung collected ('000 t)	% of dung used total	% of dung used collected
2776.627	982.303	44.7	15.8
		(nationwide average)	

Table 9 shows the achievements of the National Project on Biogas Development in recent years.

Table 9

Trends in Biogas Development

(Number of biogas plants)

	Cumulative till 1984-85	Additional 1986-87	Target 1987-88	Additional: Target April-Dec. 1987	Additional: Achievement April-Dec. 1987
Total	4,57,100	1,50,150	1,20,900	48,360	70,239

In order to improve the performance of family-sized plants, measures such as technical improvements in design, training support, repair and maintenance facilities, and regular monitoring and evaluation have been adopted. The cost of biogas plants continue to be subsidized. There is a need for further R&D inputs before its techno-economic viability is fully established. A total of 350 biomass gasifier systems had been installed in the country as on 29.2.1989. Of these, 233 systems were installed in 1987-88, indicating substantial efforts at demonstration and dissemination by DNES. Under the demonstration programme, DNES has taken up projects amounting to 5 MW of total capacity comprising both motive power application and electrical power generation. The budget for energy plantations and gasifier demonstrations during 1987-88 was Rs 4 crores. DNES has launched a systematic effort at evaluating system performance, user response, etc., the outcome of which would be useful in deciding the future emphasis on R&D and systems engineering.

2.7 ENERGY CONSUMPTION IN MANUFACTURING INDUSTRY

The industrial sector (manufacturing industry) in India has traditionally been the largest consumer of commercial energy in the Indian economy. In 1987-88, about 35 per cent of the total commercial energy available was consumed by the industrial sector. In terms of total final consumption of commercial energy, it was approximately 51.4 per cent. The contribution of non-commercial energy sources, such as bagasse, rice husk and solar energy to this sector is negligible.

In 1987-88, about 542 trillion kilocalories of commercial energy was consumed by industry as purchased fuels and electricity. Coal, oil and gas accounted for about 88 per cent of the total energy used in industry; the rest of the commercial energy was from electricity.

Table 10 presents the breakup of energy consumption in the industrial sector for 1987-88. Since 1980-81, the overall industrial consumption has grown at an annual rate of approximately 6 per cent.

Table 10

Break-up of Commercial Energy Consumption in Industrial Sector

(1987/88)

Energy Form	Quantity	Mtoe	Energy, 10^{12} kcal	% of total
Coal	80.22 Mt1/	39.308	400.9	74.0
Oil	7.269 Mt2/	7.063	72.0	13.3
Natural Gas	268 M cu.m	0.23	2.3	0.4
Electricity	78,010 MkWh	6.501	66.4	12.3
Total		53.102	541.6	100.0

Mtoe - million tonnes of oil equivalent

1/ Includes coking coal including the quantity imported, and coal used as feedstock

2/ Excludes oil used as feedstock, but includes LPG used as fuel

In 1987-88, the industrial sector consumed about 44.6 per cent of the total coal consumed in India. For oil the corresponding figure was 16.2 per cent, for gas 7.2 per cent, and for electricity, approximately 48.8 per cent. This data is given in Table 11. The oil, gas and electricity consumption in industry has been growing more rapidly than that of coal. While the share of oil and gas in the total national energy consumption has been increasing, that of electricity in industry has been decreasing steadily albeit slowly.

Table 11

Commercial Energy Consumption in Industrial Sector vis-a-vis National Commercial Energy Consumption

(1987/88)

Energy Form	Nation (Mtoe)	Industry (Mtoe)	% of Total
Coal	88.196	39.308	44.6
Oil	43.724	7.063	16.2
Gas	3.216	0.23	7.2
Electricity	13.322	6.501	48.8

In the document indicating the energy perspectives for 2004-05, the Advisory Board on Energy (ABE) has estimated electricity demand for the industrial sector at 280 billion kWh and 367 billion kWh for 1999-2000 and 2004-05 respectively. If these estimates are to hold, the demand for electricity in 1994-95 can be interpolated to be around 185 billion kWh, showing an increase of almost 50 per cent during the 8th Five-Year Plan period.

Coal use in the industrial sector is mainly in the form of coking coal for steel industry and non-coking coal for cement, paper and paperboard, newsprint and brick industries. If there was to be no improvement in the efficiency of coking coal use in industry, the demand in the years 1994-95, 1999-2000 and 2004-05 would be 60, 75 and 88 million tonnes respectively.

In the case of non-coking coal, more efficient processes, and changes in the raw materials used in cement, nitrogenous fertilizers and pulp and paper industries are expected to bring about a reduction in the quantum of coal consumed.

If the present trend of consumption of oil products per rupee of value added by the industrial sector is to continue unchanged, the demand in the year 2004-05 would be about 17 Mt of petroleum products.

On the basis of the above projections, the predicted demands for electricity, coal and petroleum products are as shown in Table 12 below.

Table 12

Future Demand Projections for Electricity, Coal and Petroleum Products in Industrial Sector

Year	Estimated Requirements		
	Coal (Mt)	Petroleum Products as Energy Source (Mt)	Electricity (billion kWh)
1989-90	89.2	6.11	120
1990-95	120.0	8.53	185
1995-2000	150.0	11.81	280
2004-05	188.0	16.62	367

Source: ABE

The growth rates represented by the above figures indicate that the demand for energy in the industrial sector for coal, petroleum and electricity may not be met. Moreover, the constraints in the supply industry are compounded by the transportation and other infrastructure deficiencies. These constraints could be tackled through energy conservation and proper management of energy resources.

2.7.1 Energy Management in the Indian Railways

The Indian Railways, with a network of 61,850 route-km and over 1,31,000 km running track, have come a long way from the modest beginning in 1853. This makes it Asia's largest and the world's third largest railway system. The operations of this network are carried out with the help of a massive fleet of rolling stock consisting of about 9,500 locomotives, 38,000 coaches and 3,54,000 wagons to meet the traffic needs of the country.

Given the size of the network and its capital outlay, a sizeable amount of commercial energy is utilized in the form of coal, diesel oil and electricity. Conventional energy in all these three forms is used for traction purposes, at stations, yards, railways colonies, workshops, sheds, and for water supply systems.

The transport sector is a core sector and accounts for about 23 per cent of the commercial energy consumption. For the year 1987-88, the total commercial energy consumption for the country was 103.35 million tonnes of oil equivalent (toe). The transport sector consumed 23.7 million toe of commercial energy, of which the Railways had a share of 5.21 Mtoe. The Railways utilize about 8 per cent of the HSD consumed in the country. The energy consumption trend for the Indian Railways over the period 1981-88 is given in Table 13.

Table 13

Total Consumption (traction and non-traction)

Year	Coal (Mt)	High Speed Diesel (HSD) oil (million litres)	Electricity (million kWh)
1981-82	10.34	1188.1	3503
1982-83	9.97	1235.6	3572
1983-84	9.53	1326.4	3711
1984-85	9.08	1378.7	3845
1985-86	8.64	1482.8	4173
1986-87	7.7	1557.2	4531
1987-88	7.0	1623.5	4730

Thus the Railways account for about one-fourth of the total energy consumed in the transport sector. Since a major portion (about 91 per cent) of commercial energy consumed by the Railways is for traction purposes, it is in this area that significant energy savings could be achieved by adopting suitable conservation measures. For this, the Ministry of Railways set a target of 5 per cent improvement in specific energy consumption for traction for the year 1988-89, which means a saving of about Rs. 65 crores.

The cost of energy is increasing every year due to escalation of fuel and electricity prices. During 1987-88, the energy bill for traction purposes alone was Rs. 1,238.57 crores. This is expected to rise to about Rs. 1,330 crores in 1988-89, constituting almost 19.5 per cent of the ordinary working expenditure. It has been estimated that in 1987-88 the saving on account of energy conservation efforts was to the tune of Rs. 53 crores. Tables 14 and 15 illustrate the decline in energy consumption in the past three years as is evident from the total energy bill as a percentage of ordinary working expenditure (OWE). Substantial energy savings have been achieved in spite of the increase in the traffic carried by the Railways in each succeeding year (see Table 16).

Table 14

Energy Bill for different zones of Indian Railways: traction energy bill vis-a-vis ordinary working expenditure

(crores of rupees)

Railways	Energy bill			Ordinary Working Expenditure (OWE)			Total energy bill as % of OWE		
	1985-86	1986-87	1987-88	1985-86	1986-87	1987-88	1985-86	1986-87	1987-88
Central Railway	182.26	206.71	208.97	685.65	766.24	860.02	26.58	26.98	24.3
Eastern Railway	138.84	155.80	159.20	684.91	762.73	880.57	20.27	20.426	18.08
Northern Railway	182.26	202.05	214.13	749.01	865.94	961.86	24.33	23.33	22.26
North Eastern Railway	53.23	63.85	60.11	267.35	311.26	364.99	19.91	20.51	16.47
Northeast Frontier Railway	29.75	37.08	36.13	224.58	263.58	306.04	13.25	14.07	11.81
Southern Railway	89.45	87.89	91.78	430.87	476.95	531.26	20.76	18.43	17.28
South Central Railway	106.51	113.28	123.53	405.88	468.93	522.99	26.24	24.16	23.62
South Eastern Railway	144.15	161.17	178.70	586.55	679.04	780.97	24.58	23.73	22.88

(Contd.)

Table 14 (Contd.)

Energy Bill for different zones of Indian Railways: traction energy bill vis-a-vis ordinary working expenditure

(crores of rupees)

Railways	Energy bill			Ordinary Working Expenditure (OWE)			Total energy bill as % of OWE		
	1985-86	1986-87	1987-88	1985-86	1986-87	1987-88	1985-86	1986-87	1987-88
Western Railway	138.95	154.64	164.36	607.20	703.97	790.00	22.88	21.47	20.17
Metro Railway	0.41	0.90	1.65	1.14	1.92	4.26	35.96	46.87	38.73
All-Indian	1065.80	1183.35	1238.57	4643.14	5300.56	6002.98	22.95	22.32	20.63

Source: Explanatory Memorandum - Railway Budget 1989-90

Table 15

Energy Bill for Non-Traction Purposes*

Year	Energy Consumption			Energy Cost (crores of rupees)			Total	As % of energy bill (traction + non-traction)	As % of OWE
	Coal (Mt)	HSD (ML)	Electricity (MKWh)	Coal	HSD	Electricity	(crores of rupees)		
1985-86	0.53	20.19	1176.89	19.727	6.95	97.211	123.889	10.41	2.668
1986-87	0.43	20.76	1288.24	17.355	5.019	132.333	154.707	11.56	2.919
1987-88	0.29	27.58	1255.92	12.879	8.440	138.905	160.224	11.45	2.670

* Based on average costs

Table 16

Total Energy Bill and Traffic Carried

Year	Total Energy Bill (in crores of rupees)	Energy Bill as % of OWE	Total Traffic Carried*	
			(in billions)	Index
1985-86	1189.69	25.62	446.5	100.00
1986-87	1338.06	25.24	479.6	107.4
1987-88	1398.79	23.30	500.6	112.1

* tonne-kilometre + passenger-kilometre

The Indian Railways have given importance to energy conservation by adopting several measures which have resulted in a decrease in the consumption of coal, diesel oil and electricity. While matters such as improved designs of locomotives and rolling stock are being tackled at the Railway Board's level and in the Research Design and Standards Organization (RDSO), Lucknow, there is large scope for saving energy at the divisional and zonal levels - in workshops, production units, stations, yards, colonies and pumping installations.

Broadly, in energy management the Railways can be divided into three areas:

(i) Conservation of fossil fuels
(ii) Conservation of electricity
(iii) Use of non-conventional energy sources

Some of the major energy conservation measures undertaken by the Railways are as follows:

Institutional arrangements have been strengthened, both at the zonal and the divisional levels, by making energy conservation a part of the responsibilities of the Additional General Manager and Additional Divisional Railway Manager, respectively. A compendium of instructions has been issued to the committees set at these levels to oversee the conservation efforts. Several long-term and short-term measures have been identified, some of which are listed below:

(i) Shutting down of locomotives lying idle in the yard

(ii) Fixing coal consumption targets for each shed

(iii) Installing shunt capacitors at traction sub-stations to improve power factor

(iv) Lubricating guage faces of rails

(v) Avoiding leakages of oil, gas, air and steam

(vi) Replacing mercury vapour lamps by sodium vapour lamps in workshops

(vii) Utilizing non-conventional energy sources - solar and wind energy - wherever possible

A quarterly report on energy conservation efforts in their respective zones is submitted by the General Manager to the Chairman, Railway Board. In fact, one of the major factors behind the good performance of the Indian Railways in the area of energy conservation is the commitment of the top management to this cause.

Accelerated phasing out of steam traction by 2000 is an important policy decision taken by the Railway Board. Retiring or phasing out steam locomotives and closure of

steam sheds have already led to a steep decrease in the consumption of coal. Apart from reducing overall consumption of energy by the Railways, avoiding haulage of coal from pitheads over long distances has also helped in saving energy. The target of phasing out 2000 steam locomotives in the Seventh Plan has already been achieved, over a year ahead of schedule.

A computerized system of monitoring locomotives individually with regard to HSD and lube oil consumption has resulted in focusing attention on the inefficient runners. The systems are fully operational at New Katni and Tughlaqabad Diesel Sheds and are being extended to other sheds in a phased manner.

Modification in design to reduce the weight of the coaches manufactured by the Integral Coach Factory by about two tonnes has been finalized.

Energy audits have been conducted in a number of major consumption areas like workshops and colonies, and others are in progress or being planned. As a result of the audits, there has been an appreciable reduction in electrical energy consumption for non-traction applications.

2.8 FUTURE ENERGY PROJECTIONS

An estimate of India's commercial and non-commercial requirements in 1999-2000 is available from the Petroleum and Natural Gas Statistics 1987-88*. The consumption of various fuels in different demand sectors of the economy are given in Table 17.

Table 17

Estimates of India's Commercial and Non-Commercial Energy Requirements in 1999-2000

	Household	Industry	Transport	Agriculture	Others	Total
Electricity (billion kWh)	81.4-83.5	249.0-282.8	8.28-8.9	40.9-41.5	44.42-48.0	424.0-465.0
Coal (Mt)	14.0	161.0	7.81	-	5.19	188.0(1)
Oil (Mt)	17.73	12.0	29.86	8.1	5.0	72.7
Fuelwood (Mt)	191.6	-	-	-	-	191.6
Dungcake (Mt)	105.0	-	-	-	-	105.0
Veg. waste (Mt)	59.0	-	-	-	-	59.0

(1) Excludes coal consumed in power sector

* The Petroleum and Natural Gas Statistics. These are more or less median values of the estimates made by the Advisory Board on Energy. This can be seen from the estimates for energy consumption by industry in 2004-05 in Tables 9 and 17.

Given the current (1988-89) levels of consumption of crude oil as 32.04 Mt, supply will have to be doubled to meet the requirement of 72.7 Mt in 1999-90. Similarly, the current level of power generation of 221.1 billion kWh falls short of current requirements by about 7.7 per cent. The total power generation capacity in 1989 was 59,600 MW, implying an overall efficiency of operation of 42 per cent. Requirements in 1999-2000 can be met only if the existing capacity operates at a load factor of 89 per cent, which is an impossible task.

However, if the plant load factor is significantly improved, the total demand could be met with reasonable expansion of capacity.

Currently, about 51 per cent of the coal consumed goes to the power plants. In 2000, it can be assumed that this percentage would increase to about 56 per cent, thereby implying a gross demand of about 300 Mt coal.

An estimate for non-commercial energy consumption reveals an increase in absolute levels of consumption. However, in percentage terms, a decrease has been registered since the early seventies. This is in spite of a large portion of the traditional fuels being used in rural households for cooking, water heating and space heating in an inefficient manner.

While the need and scope for energy conservation in industry cannot be overemphasized, it would be illogical to suppose that industrial units would invest in such schemes without incentives. Government interventions, which are both direct and indirect, are a prerequisite for the successful implementation and adoption of energy conservation schemes.

Currently, there is no energy policy in India. However, many expert committees have formulated policy guidelines to tackle the energy-related issues. Here are some of the major policy recommendations with respect to the energy sector made to the Government:

1. Concerted effort at technology upgradation and process rationalization towards greater fuel efficiency.

2. Better management of energy resources in the production and distribution processes of the energy supply industry.

3. Comprehensive pricing policy evolved so as to reflect the true cost of energy. Direct subsidies could be granted to the poorer sections of society to ensure the optimal utilization of energy.

4. An integrated rural energy planning programme to be brought forth to optimize energy consumption in the rural areas.

5. Small hydropower stations set up to complement the supply of energy at a fraction of the usual investment cost.

2.9 ENERGY CONSERVATION POLICIES IN INDIA

The policy instruments adopted so far by the Government of India to promote efficient use of energy in the industrial sector can be divided into two categories, viz. (1) fiscal or economic measures, and (2) liberalization of import of certain energy-efficient equipment.

Fiscal Measures

In February 1982, Government announced a 100 per cent depreciation allowance, effective from April 1983, on certain energy-saving devices and systems. These can be categorized as follows:

(i) Specialized boilers and furnaces

(ii) Instrumentation and monitoring systems for monitoring energy flows

(iii) Waste heat recovery equipment and cogeneration systems

(iv) Power factor-correcting devices.

Depreciation at 30 per cent has also been allowed for renewable energy devices, which include:

(i) Solar energy devices

(ii) Wind mills and related equipment

(iii) Biogas plants and engines

(iv) Battery-powered or fuel cell-powered vehicles

(v) Agricultural and municipal waste conversion devices

(vi) Equipment for using ocean waves and thermal energy

(vii) Machinery and plants for the manufacture of any of the above items.

Schemes from Financial Institutions. Both the Industrial Development Bank of India (IDBI) and the Industrial Credit & Investment Corporation of India Limited (ICICI) have introduced two schemes, viz. (a) Energy Audit Subsidy (EAS) Scheme, and (b) Equipment Finance for Energy Conservation (EFEC) Scheme. The schemes will be initially in operation for a period of two years up to the end of the Seventh Five Year Plan.

Under the EAS scheme, subsidies of up to Rs. 10,000 and Rs. 1,00,000 on preliminary and detailed energy audits would be available. The assistance under the EFEC scheme would be in the form of a term loan, up to a maximum of Rs.4 crores per company/undertaking at a maximum interest rate of 14 per cent. The interest rate will be reduced by up to 4 per cent depending on the actual percentage reduction in specific energy consumption values.

Schemes from Petroleum Conservation Research Association (PCRA)

a. Energy Audit Subsidy Scheme

PCRA offers subsidies of up to 50 per cent of the cost towards conducting an energy audit at industrial premises, limited to a maximum of Rs. 25,000 per industrial unit. The above subsidy would be payable after the acceptance of the energy audit reports, both by PCRA and the party, after a written commitment from the latter to implement the recommendations that would result in the realization of around 50 per cent of the energy saving potential identified in the report.

b. Boiler Modernization Scheme

The PCRA has an incentive scheme for investments in boiler modernization.

2.9.1 Energy Equipment

Under the import-export policy of the Government, permission in the form of an import license is usually required for import of capital goods and equipment, spares, raw materials, finished goods, etc. However, the import of certain goods is allowed free of import license. These are items classified under the Open General Licence (OGL) category. Since April 1983, import of the following energy conservation equipment, including systems and devices working on/used for renewable and alternative sources of energy, has been allowed under OGL.

(i) Wind-driven generators

(ii) Solar energy equipment

(iii) Parabolic focusing systems of the automatic electronic tracking type, including photo-electric sensors

(iv) Portable exhaust gas and combustion analyzers

(v) Steam trap leak detector

(vi) Ultrasonic steam leak detector

(vii) Solar heat control film

(viii) Burners (a few types)

(ix) Infrared thermography instruments

(x) Furnace oil flow meters and steam flow meters

(xi) Low-maintenance steam traps

Specified equipment in categories (i) and (ii) above is fully exempt from customs duty. Import of the other items is subject to payment of customs duties and levies at prevailing rates.

Complete details of the above incentives, applicable to industry, are given in Appendix I.

2.9.2 Other Measures

Apart from the above mentioned policies, the Government has proceeded along two other avenues.

Two governmental organizations - the National Productivity Council (NPC) and PCRA - offer a range of energy conservation services and assistance.

In addition, from time to time, the Government of India has constituted expert groups to examine specific aspects of energy supply and demand, and to recommend appropriate policy measures. The four groups appointed in recent times include (1) the Working Group on Energy Policy appointed by the Planning Commission, (2) the Committee on Power, (3) the Inter-Ministerial Working Group on Utilization and Conservation of Energy and (4) Advisory Board on Energy (ABE).

ABE's activities have included formulation of a set of recommendations in various areas of energy conservation, which include power and the industrial sector.

The recommendations of these groups have been published, and some of these are discussed below.

2.9.3 Policy Recommendations for India

The reports of the previous government-appointed committees had, understandably, a greater emphasis on the various aspects of energy supply. The more recently-constituted expert groups have focused considerable attention on energy consumption and conservation aspects, with growing recognition of their importance and of conservation as an alternative source of energy.

Some of the important recommendations of the expert groups and by other experts in this field are given below. (References to expert groups are shown against the respective recommendations, and the names of these groups are given in footnotes.)

a. Technical and Operational Measures

- Detailed energy audits should be carried out in at least all large and medium-sized industries.[1/]

- Measures to improve the efficiency of energy utilization in industries should be the most important element of energy policies in the industrial sector. Standards for fuel efficiency for each type of industry should be fixed with gradual improvement in efficiency over time, and their achievement monitored.[2/]

- Special attention should be paid to savings in the use of oil. Substitution of oil with other types of fuel including coal should be actively pursued[2/]

- Cogeneration possibilities in existing industries should be identified and pursued, if necessary by providing financial incentives.[2/]

b. Fiscal and Economic Measures

- Investments and subsidies for energy conservation schemes should be created, to be expanded to around Rs. 100 crores every year, over a span of 10 years, by levying an energy conservation cess on industrial consumption of petroleum products, coal and electricity.[3/]

- Customs duty relief on both components and equipment should be offered.[3/]

c. Energy Pricing

- Energy pricing policies must ensure that (i) sufficient surplus is generated to finance energy-sector investments, (ii) economies in energy use are induced, and (iii) desirable inter-fuel substitution is encouraged.[2/]

- Energy prices should be raised so that they at least reflect long-run marginal costs and allow for a

reasonable return. A further increase in the form of a conservation cess may be desirable to promote conservation of resources and economy in general use.[2/]

- The energy pricing system should be structured so that the price to the user reflects the real costs of supplying energy.[2/]

- Penal levies on industries exceed the prescribed that norms of consumption and fiscal incentives for those who improve on them should be considered.[4/]

d. Industrial Licensing, Production and Growth

- Before new units are licensed, the capacities of the existing units and the capacity utilization factors for these units should be taken into consideration.

- In setting up new industries, the technologies used should be the least energy-intensive options, particularly with respect to the use of depletable sources of energy and electricity.[2/]

- The possibility of utilizing waste heat from power plants, especially the large super thermal stations, by setting up appropriate industries in the vicinity should be seriously considered.[2/]

e. Organizational Measures

- In large and medium-sized industries, it must be made mandatory to appoint energy managers, who are suitably trained. In small-scale industries, a mechanism of energy auditing, reporting and improvement in energy use should be instituted.

f. Energy Equipment

- Better standards for various energy-using equipment must be set.

- Restrictions must be placed on the production and sale of low-efficiency motors and transformers.[4/]

- Manufacture of sophisticated instruments required for monitoring energy flows must be encouraged. Import of such instruments and spare parts should be free of customs duty.

g. Research and Development

- Each major industrial process should be reviewed to identify the R&D efforts required to reduce energy consumption.[2/]

- R&D programmes in energy conservation technologies should be sponsored by the government as a distinct component of its science and technology plan.[3/]

h. Other Measures

- Formal training courses for developing energy conservation expertise should be introduced in various technical institutions to maintain a steady flow of experts in the field.

- A system of governmental recognition and awards should be instituted for honouring individuals and organizations for outstanding performance in energy conservation 3/

- To create energy conservation awareness, pamphlets in regional languages, suitable documentary films and programmes on radio and television should be introduced. 3/

2.10 SUMMARY

India has fairly large reserves of coal. At the present levels of production, they are expected to last about 265 years. However, India lacks high quality coal the requirements of which have to be met by imports. Hydrocarbon reserves, however, are not expected to last more than 20 years and with no new oil-field discoveries in recent years the future appears grim. The reserves of natural gas are expected to last longer, i.e. 44 years. But if they are tapped at a higher rate in coming years (with the commissioning of downstream facilities) the R/P ratio might be considerably lower. Generation efficiencies of both hydro and nuclear energy are low, i.e. 42 and 50 per cent, respectively. Inefficiencies in energy consumption would have serious repercussions not only on the energy sector, but on the entire economy. Energy conservation and management are prerequisites for ensuring that the country's energy supplies last longer. Per capita energy consumption in India is fairly low and within this industrial consumption accounts for the largest share. Technological improvements, streamlining of processes, and management and efficiency of operation are required to curtail energy consumption without interfering with the developmental process. Unless the energy consumption per unit of value added is closely monitored, energy consumption can only be expected to increase in future.

Given the scenario of limited resources, consumption inefficiencies and burgeoning requirements of a developing economy, it would be natural to expect the government to have a well conceived and executed set of policies to tackle the situation. This has not been the case. The Indian Government has only ad hoc incentives and disincentives to promote energy conservation. What is really required is an integrated approach to the problem.

1/ Advisory Board on Energy
2/ Working Group on Energy Policy
3/ Inter-Ministerial Working Group
4/ Committee on Power

APPENDIX I

ENERGY CONSERVATION INCENTIVES*

Incentives currently available to encourage energy saving are listed in this Appendix.

FISCAL INCENTIVES GIVEN BY CENTRAL GOVERNMENT

A. INCOME TAX

1. One hundred per cent depreciation allowance on written-down value is allowed on energy saving devices and systems listed below:

   (Item IIIF(2A) under Part I of Appendix I to the Income Tax Rules 1962, effective from April 1983)

   (a) Specialized boilers and furnaces

   i. Ignifluid/fluidized bed boiler

   ii. Flameless furnaces

   iii. Fluidized bed type heat treatment furnaces

   iv. High efficiency boilers (thermal efficiency higher than 75 per cent in case of coal-fired boilers and 80 per cent in case of oil/gas-fired boilers).

   (b) Instrumentation and monitoring systems for monitoring energy flows

   i. Automatic electrical load monitoring system
   ii. Digital heat loss meters
   iii. Microprocessor-based control systems

   (c) Waste heat recovery equipment and cogeneration systems

   i. Economizers and feedwater heaters
   ii. Recuperators and air preheaters
   iii. Backpressure turbines for cogeneration
   iv. Heat pumps
   v. Vapour absorption refrigeration systems
   vi. Organic Rankine-cycle power systems
   vii. Low inlet-pressure small steam turbines

   (d) Power factor correcting devices

   i. Shunt capacitors and synchronous condenser systems.

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* Source: Energy Conservation, Challenges and Opportunities. Advisory Board on Energy, Government of India (1986).

B. CUSTOMS DUTY

Import duty in respect of the following 15 specified energy conservation equipment has been reduced to 40 per cent (35 % + 5 % auxiliary) ad valorem vide Notification No. 30/88 Customs, dated March 1, 1988.)

Sl. No.	Description
1.	Flameless furnaces for reheating and heat treatment applications
2.	High velocity recirculating furnaces for reheating and heat treatment applications
3.	Low excess air burners (below 10 % excess air)
4.	Fuel oil emulsion burners
5.	Regenerative burners for applications in forging and heat treatment furnaces
6.	Self-recuperative burners (burners using preheated air)
7.	Flat flame burners
8.	Heat pipes for extracting heat from low temperature fluids and gases
9.	Heat pumps for space heating, water heating, cooling applications
10.	Free-ball bucket steam traps with no links/ hinges.
11.	Automatic microprocessor-based load demand controllers for efficient load management
12.	Microprocessor-based combustion control system for boilers
13.	Light sensitive time switches for street light controls
14.	Microprocessor-based automatic anode over-potential controllers in caustic, chlorine and aluminium industries
15.	Microprocessor based-universal programmable timers for continuous and batch processes, such as in tyre industry and rayon industry.

C. OPEN GENERAL LICENSE CATEGORY

Since April 1983, the import of the following energy saving/ conservation equipment, including systems and devices, has been allowed for all persons, under the open general license (OGL) category.

- i. Portable exhaust gas and combustion analyzers
- ii. Steam trap leak detectors
- iii. Ultrasonic steam leak detectors

In the new Import-Export Policy of 1988-1991 (announced on March 30, 1988), the following items have been brought under OGL:

Capital Goods

- i. Machinery and equipment for manufacture of energy-saving lamps having efficiency of more than 60 lumens/watt

- ii. Machinery and equipment (excluding furnaces) for the manufacture of fluorescent lamps, sodium vapour discharge lamps and mercury vapour lamps

Energy Conservation Equipment

1. Burners

   - a. Zero and low excess air burners
   - b. Emulsion burners
   - c. Self-recuperative burners
   - d. High velocity burners
   - e. Flat flame burners
   - f. Axial flow burners

2. Instrumentation

   - a. Infrared thermography instruments

   - b. Furnace oil flow meters and steam meters (volume-shedding and turbine-type)

3. Other Equipment/Items

   - a. Low maintenance steam traps

Projects

1. Describe a scenario for the optimal utilization of natural gas.

2. Devise a rational system for energy pricing.

3. Discuss the techno-economic viability of renewable energy technologies in general, and in industry in particular.

4. Formulate a set of energy conservation policies for the industrial sector. Provide justification for each option.

5. Discuss the optimal fuel-mix for the Indian economy in terms of availability, prices and repercussions on the import bill, environment, etc.

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CHAPTER 3

NEED FOR ENERGY CONSERVATION

CHAPTER 3

NEED FOR ENERGY CONSERVATION

The two oil crises in 1973-74 and 1978-79 have clearly illustrated the vulnerability of nations to increasing uncertain supplies of oil. For a country like India, which is struggling to industrialize and improve the standard of living, the picture appeared bleak. Since the early eighties, most countries have taken steps to increase their energy supply, substitute imported fuels with indigenously available fuels, and conserve commercial forms of energy through policy measures.

However, on the supply side, especially that of commercial fuels, no easy solutions have arisen. The supply option, though considered to be a soft option, is increasingly becoming more expensive. Since the Bombay High oil and gas discovery, there has been very little success in finding large, new oil and gas fields. A similar situation exists in the case of coal, lignite and electricity. In the case of coal, the quality has been declining - in some instances more ash than coal is being mined, transported and used. Electricity supply options are vigorously being pursued by Government now. Despite large capacity additions in the Seventh Plan period, the gap between demand and supply has been growing as illustrated in Table 1.

Table 1

Power Deficit

Year	Deficit	
	GWh	%
1984/85	10,420	6.7
1985/86	13,480	7.9
1986/87	18,080	9.4
1987/88	23,020	10.9
1988/89	15,670	7.7

Against this background, large supplies of alternate fuels and renewable energy becomes imperative. However, availability of technology and equipment, and cost are the major constraints in exploiting alternate fuels and renewable energy. Solar, wind, tidal, geothermal and other renewable energy forms are not expected to make a significant dent in the energy scene until well into the next century.

Steady expansion of nuclear power seems like a viable solution. Again, in India the progress in this direction has been very slow. Additional safety measures and increasing public lobby against nuclear power are adding to the cost of nuclear power, and result in undue delays in project completion.

Against this rather pessimistic short-term picture, energy conservation emerges as an extremely important energy alternative. This is one of the supply options which is cost-effective, least polluting, and has other indirect benefits. Our degree of success in achieving greater energy efficiency will largely influence the extent to which we manage the energy problem successfully.

Over the longer term, short-term demand restraint actions must evolve into long-lasting structural alterations in the way in which energy used. This would call for structural changes in the Indian economy, and energy sectors. For example, oil may be replaced in sectors where substitutes are technically and economically feasible, such as in manufacturing industry and electrical generation. It will also have to include meaningful, sustained actions that will increase standards of efficiency in the industry, transport, residential, commercial and agricultural sectors.

The transition to an energy-efficient economy will not be an easy task. A leader in this process has to be industry as over 50 per cent of the net available commercial energy for consumption is used. There are indications that increased prices, lack of availability, poor quality of supply and increased awareness have resulted in providing a stimulus for significant energy savings. Yet industry is faced with the perplexing problem that the cost of energy in some processes, although important, may only be a small part of the cost of the final product. The cost trade-offs in many cases have led to accepting higher energy prices rather than optimizing the production process under the new circumstances. Responsive government actions, such as financial incentives, have been successful in overcoming part of this problem, but the primary responsibility rests with industry.

More efficient use of energy by industry will not only help cost effectiveness, but will also contribute substantially to improved prospects for the economy. Inaction by industry now can result in energy shortfalls tomorrow, negatively affecting macroeconomic growth over the medium-term.

The energy crisis is here to stay with us. It is also real, substantial, and will likely be long lasting. Energy costs are rising rapidly, conventional energy

supplies are diminishing, alternate sources are still evasive, and previously secure energy sources are highly questionable. With this myriad of energy-related problems, prudent management of any organization would initiate and conduct energy management programmes.

India is one of the largest countries in the low-income group of countries. The average annual growth rate (AAGR) of primary energy demand per unit of GDP in 1984-85 was 1.4 per cent, and is still positive indicating that India is in the process of industrializing with an aim to improve the standard of living of its masses. However, energy efficiency has not received much attention. While China has a much higher primary energy demand per unit of GDP than India (1.4 against 0.79), the AAGR in 1984-85 was (-)1.3 per cent. At present the trend is maintained in China. The above data is shown in Table 2. In contrast many developing countries, many developed coun-tries have already shown the possibility of delinking energy consumption and GDP.

Table 2

Primary Energy Demand Per Unit of GDP

(toe per thousand 1980 US dollars)

Category	Country	1984/85	AAGR*
Low-income	Pakistan	0.64	+4.2
	Senegal	0.49	+3.6
	India	**0.79**	**+1.4**
	China	1.40	-1.3
Lower middle-income	Nigeria	0.18	+9.4
	Cote d'Ivoire	0.13	+2.8
	Thailand	0.38	-0.8
	Philippines	0.35	-2.7
Upper middle-income	Venezuela	1.40	+4.6
	Mexico	0.56	+2.2
	Brazil	0.68	+2.1
	Argentina	0.29	+1.8
Industrial Market	Australia	0.45	-0.5
	Federal Republic of Germany	0.31	-1.7
	Netherlands	0.36	-1.7
	United Kingdom	0.35	-2.0
	United States	0.61	-2.2
	Japan	0.29	-3.1

* AAGR = average annual growth rate (per cent)

Souce : OECD Energy Balances and Shell International, 1988

3.1 ENERGY MANAGEMENT

Energy management in a broad sense includes reduction of energy per unit of product, changing from a scarcer energy source to a more readily available one, feedstock changes and recycling of waste.

Energy management can also be defined as the judicious use of energy to accomplish prescribed objectives. For an industrial unit, these objectives are normally to ensure survival, maximize profits, and enhance competitive positions. In short, energy conservation is good business and makes a lot of sense.

Unfortunately, Indian industry has not responded adequately to the call for efficient energy management. The organizations which have achieved success in this task are few, and yet have a large potential for saving energy. Our industry has been plagued by a series of problems ranging from lack of top management commitment to poor housekeeping. Fortunately there are technical and managerial solutions.

Table 3 provides a comparison of specific energy consumption values in steel, cement, pulp and paper, and fertilizer industries, for India and six developed countries in the year 1983. The values shown in the table have improved only marginally since 1983. In the case of steel and cement, the average specific energy consumption in India was more than two times that of Italy and Japan. The specific energy consumption values of pulp and paper and fertilizer industries in India again point out that there is a large scope for improvement.

Table 3

Specific Energy Consumption in Selected Industries
in India as Compared with those of Developed Countries
(1983)

(million kcal/tonne)

	Steel	Cement	Pulp & Paper	Fertilizer
India	9.50	2.00	11.13	11.25
Italy	4.03	0.89	-	9.92
Japan	4.18	1.20	-	-
Sweden	5.02	1.4	7.56	-
UK	6.07	1.3	7.62	12.23
USA	6.06	0.95	9.70	11.32
West Germany	5.21	0.82	-	-

Energy conservation measures in industry are economically very attractive. This is true at the unit level as well as at the national level. It is clear from Table 4 that the investment required to create additional energy supply is much higher than that required for energy conservation measures. The annual energy savings is at an overall return of over 50 per cent. It is important to note that most of the short-term measures require very little investment, and have payback periods ranging from a few days to 2 years. Long-term measures generally require large investments, and payback periods range from 2-5 years. This can be seen from Table 5 in which a break-up of investment and expected savings of Table 4 are given.

To the question as to how much energy savings is possible, most companies find that 5-15 per cent is easily achievable, mostly through housekeeping and short-term measures. A dedicated programme yields 30 per cent, and some companies have the potential of reaching 60 per cent. The potential for substantial cost reduction is real, and energy saving opportunities would never end as more new efficient technologies and methods of operation are found.

Table 4

Manufacturing Industry - Conservation Potential (1983)

Energy Form	Annual Consumption (million tonnes)	Savings* Potential (million tonnes)	Investment Required for Creating Equivalent Resource (Rs. million/ unit)	Total Investment Required (Rs. million)
Coal	70	17.5	50	875
Oil (As Fuel)	4	1.0	180	180
Electricity	60 billion kWh	5250 MW	0.9	4725
Total investment for creating equivalent energy capacity				5780
Investment required for implementing energy conservation measures				3600
Annual expenditure saving in industrial sector by implementing conservation measures				1925

* By means of short- and medium-term measures.

Source: IMWG's Summary Report on Utilization and Conservation of Energy, September 1983.

Table 5

Manufacturing Industry - Conservation Potential
Savings from Energy Conservation Measures

(1983)

Energy Conservation Measure	Investment (Rs.crores)	Expected Savings (Rs.crores)
Short-term measures	400	616
- Good housekeeping - Training of personnel - Energy audit		
Medium-term measures	1200	772
- Waste heat recovery		
- Inefficient boilers' replacement		
- Instrumentation and control systems		
- Technological innovations, e.g., ceramic fibre insulation, low excess air burners, variable speed drives, etc.		
Long-term measures	2000	537
- Cogeneration		
- Newer energy-efficient technologies		
- Computers for process control		
Total	3600	1925

The future demand for electricity, coal and petroleum products in industry shown in Table 9 of Chapter 2, cannot be met through supply augmentation alone. Energy conservation has to play an important role in future if the demands were to be met. Otherwise, there could be crippling energy shortages in manufacturing industry.

3.2 ENERGY AND ENVIRONMENT

By close examination of the problem, we find that we are on the path of diminishing returns in the use of most energy sources on the horizon: larger capital and energy expenditures, costly and even elusive research and developmental goals, and the prospect of greater environmental degradation. Among the most critical problems that the world faces today, the important ones are environmental pollution and the effects of depleting natural resources. To ensure that energy resources last longer and pollution is reduced, all energy resources must be used efficiently, i.e., energy must be conserved. Even if we look at the pollution aspect alone, it is necessary that we examine our energy use patterns to improve energy efficiency and curtail waste.

We are at the crossroads where energy choices we make now will determine what kind of natural heritage we leave behind to future generations. As population of the nation expands, so does our demand for energy, which would make the task of pollution control more difficult.

Industrial Sector

There are three by-products of energy production and consumption - heat, particulates and gases - which have the potential for inadvertent modification of global climate. It has been known for some time that cities create their own microclimate. Increasing urbanization, large power generating stations and power parks, and similar developments might, by their output of heat and particles, disturb rainfall or influence other meteorological phenomena on a global scale. However, studies have shown that the simple product of combustion, carbon dioxide*, has the greatest apparent potential for disturbing global climate over the next few centuries.

Carbon dioxide, although virtually transparent to shortwave solar radiation (visible light), strongly absorbs long-wave radiation (heat) at certain wavelengths where other atmospheric gases are transparent. In the atmosphere, it impedes radiation of heat from the earth's surface into space. An increase in carbon dioxide concentration in the atmosphere could disturb the balance between incoming solar radiation and the radiation of heat from the earth into space with a resulting increase in the temperature of the lower atmosphere. Because glass in a greenhouse traps the sun's heat, although mainly by preventing convection, this phenomenon has come to be known as the greenhouse effect.

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* The present level of carbon dioxide concentration in the atmosphere is 0.034 per cent by volume. Since the beginning of industrialization, the carbon dioxide concentration in air has gone up by about 25 per cent.

The impact of particulates and release of large quantities of thermal energy which creates 'hot spots' cannot be discounted. However, it would be difficult to predict this impact as models currently available are not adequate.

It may be argued that if the potential for climatic change due to the by-products of energy production and energy use is substantiated through research, then it may be necessary to reverse the trend in consumption of fossil fuels. Alternatively, carbon dioxide emissions will somehow have to be controlled or compensated for (no practical means of doing so seem to be readily at hand except through photosynthesis). In the face of so much uncertainty regarding climatic change, it might be said that the wisest attitude is to continue doing what we are doing now. Unfortunately, it will take a millennium for the effects of a century of use of fossil fuels to dissipate.

If the decision is postponed until the impact of man-made climatic changes has been felt, then, for all practical purposes, the die will already have been cast.

The two major by-products of coal combustion, sulphur dioxide (SO_2) and particulate matter have been of environmental concern for many years, especially in the U.S., Canada and Europe. SO_2 is formed when sulphur in coal is combined with oxygen in the air during combustion. When released into the atmosphere, the SO_2 combines with water vapour (H_2O) to form sulphuric acid (H_2SO_4). This when precipitated as rain is called acid rain. Nitric oxides (NO_x) produced from the heating of air during combustion, is also a major concern, as it also changes to nitric acid (HNO_3) in the atmosphere, which finally precipitates as acid rain.

Acid rain is a worldwide concern. It was reported in 1983 that as much as 35 per cent of the Black Forest in West Germany has been damaged by acid rain. Excess acid in rain also affects aquatic life in lakes and ponds, and damages monuments and buildings. The effect on humans is not clearly understood.

Energy conservation measures, in general, have a positive effect on the environment by reducing the amount of pollutants discharged from any energy conversion process. The effect of any energy conservation measure on the environment depends primarily on the type of measure, the type of industry where it is applied and the quantity of energy saved.

For example, in cement industry the change from wet process to dry process, there is a significant reduction in the thermal energy use; this in turn results in a reduction in airborne pollution.

In the caustic soda industry, a change from mercury amalgam cells to membrance or diaphragm cells results in total elimination of mercury pollution on soil and streams. Moreover, the membrance and diaphragm process results in electricity saving of about 25 per cent. Therefore, pollution from source power plant is reduced.

The current oil import bill is nearly Rs. 8,000 crores and it adversely affects the foreign exchange position. As there is a clear need to reduce oil imports to save foreign exchange, Government has resorted to a drastic measure of closing petrol stations in cities and towns part-time on Sundays. However, the same expected results could have been achieved by conservation, and better management of our resources.

In the Eighth Plan, the allocation for the energy sector is expected to be much higher than the same for the Seventh Plan. The power sector is expected to get Rs.128,000 crores* as against Rs.34,273 crores in the Seventh Plan. The magnitude of the plan allocations for energy sector indicates that the other vital sectors of the economy would get much less than what is needed. Therefore, there is an urgent need for sound energy management leading to less allocation for the energy sector, and more for others.

3.3 SUMMARY

There is a clearcut need to conserve energy in industry in India as the present energy efficiency is very low indicating a large potential for saving. There are many environmental benefits due to energy conservation. In most cases, energy conservation measures are economically more attractive, and have smaller gestation periods than new energy supply projects. Energy conservation is good business at the enterprise level, and economically attractive for the nation.

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* Not finalized at the time of writing.

CHAPTER 4

ENERGY MANAGEMENT CONCEPTS

CHAPTER 4

ENERGY MANAGEMENT CONCEPTS

4.1 WHY ENERGY MANAGEMENT ?

Energy is a vital input to all operations of the Indian Railways including traction, production units and maintenance workshops. The energy management concepts provided here essentially applies to Railway workshops and production units. However, many of the energy management concepts can be applied to the other operations of the Railways, with modifications wherever required. The large potential for saving energy use in the Railways workshops, the increasing problems of energy supply, and the rising costs of energy point to the use of energy management at the workshop level as a sound strategy to reduce costs and improve productivity. In most cases, energy management can lead to 15-20 per cent savings in the short- and medium-term with low requirements of capital investments. These savings can generally be achieved irrespective of the size of the workshop and the activity it is engaged in.

The following describes the approach and considerations that go into developing a programme for rational use of energy at the workshop level. Broadly, this comprises four phases:

- Establishing a management structure for energy management

- Initiating energy management activities

- Managing the programme once it is under way

- Maintaining energy management activities permanently

Guidelines given in this chapter for setting up an energy management programme in any workshop of the Railways are by no means rigid. However, the methodology set out here has been tried in many industrial organizations and found to be successful.

4.2 ORGANIZING ENERGY MANAGEMENT

The most essential requirement for a successful energy management programme is the commitment and dedication of the top management at each of the workshops. They must be totally convinced of the need and benefits of energy management. They must be willing to provide the resources, both personnel and capital. They must visibly demonstrate and communicate their commitment to the employees of the workshop.

Since the Indian Railways have already taken a decision to start an energy management programme, a special management structure within the organizational framework needs to be created in view of the special role of energy as a common input across different departments and sections.

The first step in this process is the appointment of a Director in the Railway Board to look after energy management. The person appointed to this post should report directly to the Chairman, Railway Board. This also serves to demonstrate to all employees the importance attached to energy management. This position requires full-time attention. The person appointed as Director, Energy Efficiency must be knowledgeable about all aspects of the Railway's operations and energy usage, committed to energy management, influential and assertive. Zonal programme manager at each of the zones of Indian Railways should also be appointed.

It is important to appoint an energy manager/coordinator at the workshop level, who would have similar background and characteristics as Director, Energy Efficiency. Appendix 1 provides various responsibilities of Director, Energy Efficiency, workshop energy manager/coordinator, workshop energy management committee, departmental energy management coordinator, and corporate energy management steering committee.

In the Indian Railways, it is worthwhile having a technical steering committee for better coordination of the Railway's overall technical programme in energy conservation. The energy management technical committee operates under the direction and guidance of the corporate energy management steering committee. The former committee would set a reference guide for ongoing activities and use of skills for all zones of the Indian Railways. It would identify common areas of concern and technical solutions that are applicable across the board. A typical organizational chart of the Railways energy management is shown in Figure 1.

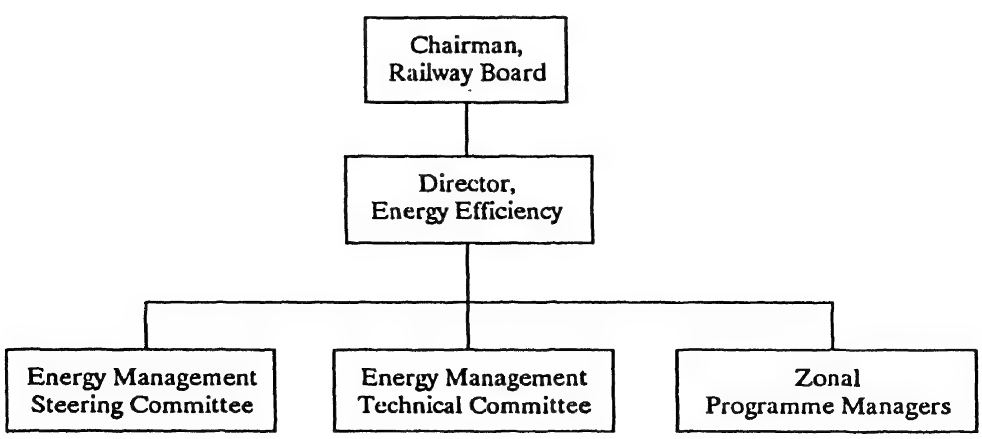

Fig. 1: Typical Corporate or Company Energy Management Programme.

A useful practice is for the workshop energy manager/ coordinator to be assisted by a committee consisting of representatives from various functional areas. This committee would assist in developing programmes and formulating plans, serve as a channel for communication back to personnel in their functional area, and also serve as a forum for review and generation of ideas. Membership in this committee could be rotated on a planned basis to involve a greater number of people and get more ideas. Fig. 2 shows a typical chart of a plant energy management organization in a medium-sized or a large workshop or production unit.

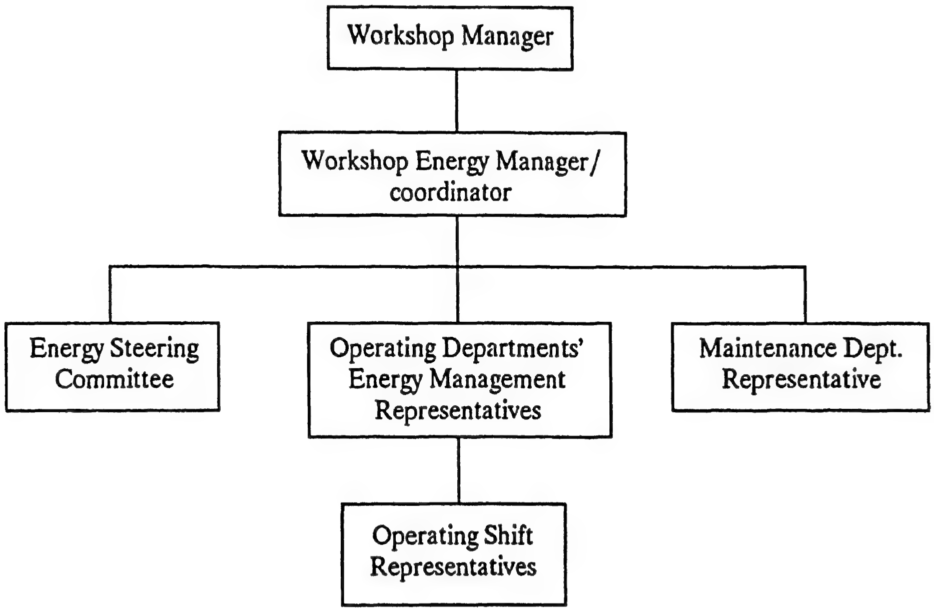

Fig. 2: Workshop or Production Unit

4.3 INITIATING ENERGY MANAGEMENT

With the appointment of a Director, Energy Efficiency, and the establishment of an appropriate energy management structure, the process of planning and initiating energy management activities can be undertaken. This comprises three major steps :

- Setting overall energy management policies

- Conducting workshop energy studies (energy audits)

- Formulating a plan of action

The above plan also applies at the workshop level.

Step 1 : Setting overall energy management policies

The first step is setting of overall policies relating to objectives, goals, methods, resources, etc. Some of the questions that should be addressed in this context are:

- **What are the objectives of the energy management programme ?** These could be minimization of energy wastage through better housekeeping, improvement of efficiency of energy consuming equipment, substitution of expensive or scarce fuels, incorporation of better operating and maintenance practices, training of all staff including operators for energy-efficient operation, etc.

- **What are the goals ?** These can be expressed in terms of expected reduction in energy consumption or energy costs over a specified time period.

- **What are the possible methods to achieve the desired objectives and goals ?** These could include workshop energy studies, incorporation of technological developments, equipment modification or replacement, streamlining of operating procedures, etc.

- **What resources - personnel and capital - are to be committed ?**

- **How will the achievement of objectives and goals be monitored ?**

Clearly, these questions cannot be answered without some knowledge and understanding of the workshop's energy consumption patterns and trends. This requires at least an analysis of historical data on the quantity and costs of various forms of energy used within the plant, and the specific consumption values or energy intensities, i.e., the ratio of energy inputs to production outputs. These analyses are very useful in highlighting major trends in energy consumption at the overall corporate or workshop level.

It would appear that some of these questions would be better addressed as the energy management programme progresses. This is indeed so. Nevertheless, it is very important, and in fact essential at the very outset to define overall policies, even in somewhat preliminary fashion, which would serve as the basis for an initial commitment. As the programme proceeds, these policies should be reviewed and revised, if necessary.

Step 2 : Conducting workshop energy studies

To save energy, it is necessary to know where, how and how much energy is being consumed. The objective of workshop energy studies, also referred to as **energy audits**, is to characterize and quantify the use of energy within the workshop at various levels - in sections, major processes, and major equipment. The energy study provides a comprehensive and detailed picture not only of the type and quantity of energy being used but also how efficiently it is being utilized, the mechanisms by which energy is being lost, and the amounts of energy thus being lost.

Workshop energy studies can be carried out in two sequential phases - a preliminary study and a detailed study.

The preliminary (workshop) energy study or preliminary energy audit is essentially, as the name implies, a preliminary data collection and analysis effort. Readily available data on the workshop's energy systems and energy-using processes or equipment is obtained and studied. The operation and condition of equipment are observed by going around the workshop and discussing aspects of these with workshop personnel. The data and observations are then blended with personal experience to develop recommendations for immediate short-term measures, and to provide quick and rough estimates of savings that are possible and achievable. A preliminary study usually identifies and assesses obvious areas for energy savings such as inefficient and insufficient lighting, poor or missing insulation, condensate recovery, idling equipment, deterioration and deficiencies in combustion and heat transfer equipment (e.g., furnace), water wastes, etc., and serves as a basis for the detailed workshop energy study.

The detailed workshop energy study is a comprehensive analysis and evaluation of all aspects of energy generation, distribution and utilization within the workshop. The analysis is based on consistent and detailed accounting of all energy inputs into a system and all energy outputs from a system which results in the development of energy and mass balances. At the workshop level, the analysis requires time-series data on a daily, monthly, or yearly basis on the quantities of all forms of primary energy flowing into the workshop, e.g., coal, L.D.O., H.S.D.O., other fuel oils and electricity, and production figures of various items. At the section level, information is required on the quantity of energy forms and utilities consumed, and the production figures of intermediate products. At the equipment level, in addition to the quantities of energy forms and material flow, process parameters such as temperature, pressure, flow, etc. are also required.

Data generation and collection are essential and critical elements of a detailed energy study. Difficulties in meeting data requirements generally arise due to unavailability of workshop operating data, inadequate instrumentation, poor accessibility of equipment, unavailability of workshop design data, and unavailability of historical records. The acquisition of actual operating data through existing or new permanently installed instruments or portable test instruments cannot be overemphasized in this context.

Measurements are critical in any serious effort to conserve energy. Apart from helping to quantify energy consumption, measurements also provide a means to monitor equipment performance and check equipment condition. Examples of measurements and instrument types are :

- Flow/Velocity: Orifice plate, pitot tube, venturi tube, turbine meter and anemometer

- Temperature:Thermometers - bimetallic, resistance, etc., thermocouple and radiation pyrometer

- Pressure: Bourdon gauge, diaphragm gauge and manometers

- Heat Flow : Thermography equipment

- Electrical: Multimeter, ammeter, wattmeter, power factor meter and light meter

Analysis and evaluation of data lead to identification of various measures that would save energy. These measures are then evaluated with regard to their technical and economic feasibility, resulting in recommendations for further action.

An energy audit is not an end in itself. It does not save energy; it merely indicates areas with the greatest potential for energy (and monetary) savings, and therefore, areas where further action needs to be concentrated. It also provides a starting point or baseline from which progress on energy conservation can be measured.

The duration of these studies depends on plant size and complexity. A preliminary energy study can be carried out in two days. The detailed study would require anywhere from three months to six months of effort.

Workshop energy studies can be carried out in-house if adequate resources and expertise are available. Alternatively, or additionally, external assistance may be sought from energy consultants, equipment vendors, and engineering and design firms. In every case, intense

interaction between personnel at the workshop and the study team is essential for a proper understanding and a meaningful analysis of the workshop's energy options. Too often, the energy study is considered to be the consultant's 'problem', resulting in minimal inputs and involvement from workshop personnel. This attitude is counter-productive and self-defeating. Without the active participation at all levels, savings in energy use cannot be expected and accomplished.

Step 3 : Formulating an action plan

In most cases, drawing implementation plans can begin even while the energy study is under way. This is particularly so for measures emphasizing better house-keeping which are usually low capital but manpower intensive options. Once the energy audit is complete, it should be carefully reviewed and a detailed implementation plan devised. At this stage, the overall energy management policies formulated earlier should also be reviewed and suitably amended, if necessary. For example, an energy audit may indicate that the goals set earlier were too low, and an upward revision may be required. Goals should be tough but realistic.

The implementation plan must include specific time schedules for specific projects or categories of projects. Individual responsibilities must also be assigned. Management must exercise due control and authority to ensure that the implementation plan is as per schedule. Periodic progress reviews at quarterly or half-yearly intervals should be carried out to assess implementation progress, to ensure that anticipated savings are being realized, to review any energy savings opportunities identified subsequently, and to assess the impact of changes in factors such as energy prices, production levels, production mix, etc. on the energy conservation programme.

4.4 MANAGING ENERGY MANAGEMENT

Having initiated an energy management programme, proper management is essential to reap the benefits that are expected. Two major elements of this managerial function are motivating employees to participate and contribute, and monitoring of progress.

4.4.1 Motivating People

Employees can be motivated to support and actively participate in an energy management programme through:

- Awareness and information

- Involvement
- Incentives and rewards
- Publicity and promotion

4.4.2 Awareness and Information

In most enterprises, employees have little or no idea of the amount of energy being consumed within their plants/workshops, their section and even the equipment being operated by them. In such a situation, energy conservation obviously carries no meaning. Employees can be stimulated to support energy management by making them aware of the amount of energy they are using, the associated costs, the many ways to save energy, the dependence of energy consumption on other factors such as production rate, and the importance of energy conservation for the company's profitability and the nation's growth. The information can be provided in the form of comparisons of historical trends, current values and goals for overall energy use, energy intensity, etc. in both physical and monetary terms; energy conservation checklists for each manufacturing operation outlining simple and routine housekeeping measures to save energy, audio-visual presentations, and other general literature.

Information must be presented in a manner which facilitates comprehension. If the information is too technical, too much, too sketchy or too dull, it is likely to be ignored or not understood. Terms that employees can relate to in everyday life should be used. For example, a sign saying 'Stop Oil Leaks' will not be as effective as a sign saying 'One drop of oil every five seconds costs Rs. 1,000 per year'.

Training is also an important means of both informing and involving people at all levels in an energy management programme. For operating personnel, training is required in energy-efficient operation of equipment and the practicalities of energy saving. This could be integrated into the workshop's other training programmes. Upper level management also need to be informed of the overall energy situation, energy costs in relation to other costs, the energy management programme - its goals, achievements, technical, economic and behavioural aspects, etc.

4.4.3 Involvement

Motivation is based on involvement. Commitment and a sense of personal accountability can be generated only through total involvement of personnel at the workshop at all stages from initiation to implementation of the energy management programme.

Involvement must begin with the top management. As mentioned earlier, top management must be fully committed to the energy management programme and must visibly demonstrate their commitment and involvement in every manner possible and at every available opportunity. Top management must originate the programme, generate momentum and then maintain momentum. Adequate personnel and financial resources must be provided and responsibilities delegated to implement activities and projects to achieve the predetermined energy conservation goals. Progress should be monitored and goals reviewed and revised in the best interest of the Company.

Supervisors should be involved by assigning them responsibilities for implementing and monitoring activities, and by getting them to interact and communicate with operations and maintenance staff on progress and problems. If possible, energy management activities should be made a part of each supervisor's performance or job standards.

Operators and maintenance staff should be involved actively as they are ultimately responsible for execution of activities in the programme. Also, they are often in a better position to recommend areas of energy savings or improvements. The most effective way of involving them is by simply going out and talking to them regarding goals, achievements, problems, and progress or lack of progress. This demonstrates to them that the energy conservation programme is real and also that their role is important in success or failure of the programme. Another means of involvement is through training.

4.4.4 Incentives and Rewards

Another method of motivating people is through incentives and rewards. Monetary rewards could be given to employees for suggestions leading to substantial energy savings, for innovative ideas or solutions, and for outstanding efforts in implementation of energy conservation activities. Wide publicity of effective ideas provides an added incentive in the form of public recognition. Other incentives could be designed to meet the needs and attitudes of workshop personnel.

One possible danger with monetary rewards is that it makes people get accustomed to receiving extra compensation for an effort that really is part of their job. If rewards are stopped later, there could be a reduction in ideas that could affect original gains.

4.4.5 Publicity and Promotion

Publicity and promotion are essential to make the energy management programme successful. Some suggestions for publicizing and promoting an energy management programme are listed below[1/]:

1. In the energy conservation newsletter, include a personal profile on people performing energy management activities and at least one good energy conservation idea that was implemented.

2. Posters and pamphlets on energy conservation.

3. Notepaper pads with different energy conservation opportunities and ideas printed on the paper.

4. Energy conservation performance results for workshop and sections are posted monthly by the workshop manager.

5. Energy manager/coordinator conducts quarterly on-site reviews, a walk-through of the unit looking for energy-saving opportunities.

6. An agenda item on energy conservation is included at staff meetings.

7. Energy conservation material is provided to supervisors for hourly employee discussion periods at least quarterly.

8. Quarterly meetings are held in the workshop for all departmental representatives.

9. Annual meetings are held by energy manager/coordinator

10. An energy awareness day is set aside in the workshop twice a year.

15. An energy logo for the entire Indian Railways is developed and adopted.

4.4.6 Monitoring and Reporting

Monitoring of the energy conservation programme is necessary to ensure that it is on schedule and that established goals and objectives are being met. Programme momentum can also be maintained through monitoring. This requires tracking of selected measures of performance.

1/ Adapted from Reference (1)

Selection of the appropriate and relevant measures is essential for proper monitoring. For example, at the workshop level, energy usage or cost trends could be tracked. However, these are not unique measures by themselves. Energy usage could also vary due to changes in production volume or production mix. Energy costs would also change due to increases in prices. A better factor is the energy intensity, or energy consumption per unit output, although even this is a function of production rate. Another method could be the use of an energy conservation index wherein current energy use is adjusted to compare with energy use in a certain base period.

Starting from the overall workshop level, monitoring should be carried out at the lowest level possible. This allows closer monitoring of progress and deviations, and faster response to overcome problem areas.

Effective monitoring requires that a reporting system be developed and instituted. Report contents and frequency should be tailored to the audience. Reports to top management could be submitted quarterly giving monetary savings, energy savings, capital expenditures and other expenses, and measures of performance such as energy intensity or energy conservation index, all shown against their goals, and a brief description of activities. Reports to workshop managers would be more detailed and more frequent, say monthly. Reports should contain more specific and detailed information at lower levels. For a few key areas, such as peak electrical demand, reporting could be on an hourly, daily, or weekly basis to monitor energy consumption or wastage more closely.

Installation of required instrumentation, acquisition of necessary data, proper maintenance of plant logsheets, and consistent energy accounting are essential for reporting and monitoring. In this context, it is important to reiterate the need for instruments and measurements not only during the energy audit phase but also during subsequent implementation of energy-saving schemes.

4.5 METERING AND CONTROL

Only main energy functions should be metered - roughly 20 per cent that make up 80 per cent of the costs. A few functions of an equipment or a system usually accounts for a majority of costs. Submetering the main functions at various load centres in the workshop can provide vital information through periodic measurements, to enable control of costs in a short time interval. The cost of metering and submetering is usually incidental to the potential for realizing significant cost improvements in the main energy functions of production systems.

4.6 MAINTAINING ENERGY MANAGEMENT

Energy management is not a one shot affair. Rather, it should be a continuing programme whose focus and strategies may change over time. The overall objectives, however, are invariant.

Results of the energy management programme should be reviewed annually to determine whether the objectives and expected savings have been achieved. Based on the review, policies should be reassessed and the plan of action revised. The energy reporting system should become an integral part of existing management information systems. Employee motivation should be sustained. Technological developments should be continuously monitored and evaluated. A frequently neglected aspect is the contribution of a good preventive maintenance programme to effective energy management. Only by sustaining the momemtum and the efforts will energy savings continue to accrue.

4.7 COST CONTROL

In addition to energy costs, it is useful to include the cost of depreciation, maintenance, labour and operating costs involved in the energy conservation equipment in providing the required services. These costs may add as much as 50 per cent to the fuel cost. It is the total cost of these functions that must be managed and controlled, not just the kcal or kJ of energy.

When energy substitution possibilities exist, for example, natural gas replacing electricity in certain heating applications, it is important to look at the average rate of increase of prices of these energy sources, before making a decision on the substitution. Here again, one should consider the total cost of energy functions rather than energy saving in kcal or kJ.

It is important to start by achieving the minimum cost possible with the present equipment and processes. Installing management control (metering and monitoring) systems can indicate what the lowest possible energy consumption in a well controlled situation. It is only at this point, when a change in process or equipment should be considered. An equipment change prior to actually minimizing the expenditure under the present system may lead to oversizing new equipment or replacing equipment for unnecessary functions.

4.8 MANAGEMENT DISCIPLINE

The major effort should be put on the energy management programme into installing controls and achieving results. It is common to find general knowledge about how large amounts of energy could be saved in a plant. The missing ingredient is the discipline necessary to achieve these potential savings. Each step in saving energy needs to be monitored frequently by the person responsible for energy conservation (energy manager/coordinator) to see noticeable changes. Logging of important fuel/electricity usage is almost always necessary before any particular savings can be realized. Therefore, it is critical that an energy manager or a committee has the authority from the chief executive to install controls, not just advise line management. Those energy managers who have achieved the largest cost reductions actually install systems and controls; they do not just provide advice.

4.9 CONCLUSION

More than ever before, energy management is the need of the hour. It is easy and simple, involving the application of well-known principles and techniques. It is also cost effective. Irrespective of the size of an organization and its operating units, an energy management programme can be initiated in a few months, and savings can be realized almost from the beginning. An energy management programme in the Indian Railways would be a sound investment with returns comparable to the best elsewhere.

REFERENCE

Williams, Milton A., Initiating, Organizing and Managing Energy Management Programs in Turner, W.C. (Ed.), Energy Management Handbook, John Wiley & Sons, Inc., Singapore (1982).

PROJECTS

1. Define objectives and goals of energy management programme in your workshop, and describe ways of achieving them.

2. Propose awards schemes (and ways to implement) for energy conservation achievements, and provide justification for each one of them.

3. Suggest and devise slogans on energy conservation for posters, signboards and stickers

4. Devise methods of monitoring energy consumption in your workshop, and suggest formats, and frequency of reporting.

APPENDIX 1

Duties and Responsibilities

Director, Energy Efficiency

1. Assembles annual energy conservation goals from workshops, and production units, and other functions, and monitors and reports progress towards meeting these goals.

2. Recommends techniques for energy audits, assists workshops and production units in coordination and reporting of energy audits, and/or recommends experts to assist in energy audits.

3. Develops techniques for improving personnel awareness of need for energy conservation throughout the Railways.

4. Recommends and implements programmes for unified reporting of energy conservation progress, including rupees and kcal/kJ savings, kcal per kg, energy efficiency index data, and Railways' and governmental energy conservation reporting requirements.

5. Provides forecasts of energy conservation for input to long-range energy forecasts for the Indian Railways.

6. Advises all functional departments in developing and using unique approaches, programmes, publicity, and reporting techniques for energy conservation.

7. Is responsible to coordinate plans and programmes of the energy managers/coordinators.

8. Establishes annual plans and programmes that will establish coordination needs for assignment of appropriate resources to achieve annual and long-term energy conservation goals.

9. Periodically monitors location and functional energy conservation goals, programmes, progress toward achieving goals, and resources assigned to achieve goals.

10. Provides annual energy conservation guidelines and recommendations to obtain challenging and achievable energy conservation goals for all locations and functions.

11. Coordinates development of annual energy conservation goals for all locations and functions to receive appropriate management endorsement for assignment of resources needed to achieve the goals.

12. Provides communications assistance in energy conservation matters to support zonal and corporate programmes as required.

Energy Manager/Coordinator

1. Reports workshop's energy conservation progress and needs to workshop management and Director, Energy Efficiency, Railway Board and monitors results.

2. Develops and communicates energy-saving techniques and ideas to operating departments' representatives (opportunity checklist)

3. Maintains close contact with plant management on problems, needed assistance, and personnel requirements.

4. Provides publicity and conducts awareness programmes for the workshop employees.

5. Visits the operating units/departments within the workshop regularly to discuss energy conservation.

6. Holds quarterly meetings of all unit/department representatives - chairs energy steering committee

7. Maintains environment that motivates employees to save energy.

8. Develops methods of monitoring critical workshop energy usages for control purposes.

9. Develops annual energy goals, programmes, budgets, and funding requirements.

10. Oversees a training programme for energy-efficient operation.

These responsibilities can be broken down into the following roles.

Line Role. Ensures that energy conservation programmes are in accordance with workshop's and Railways' objectives.

Coordinating Role. Develops and recommends objectives; goals, standards, and procedures for the workshop energy conservation programme.

Advisory Role. Provides information to workshop managers; operating departments; Director, Energy Efficiency, Railway Board; other workshops; and outside agencies on conservation matters that affect them.

Service Role. Provides service to workshop manager by moitoring and reporting energy conservation. Provides service to all line and staff functions within the workshop through resource information and guidance on matters related to energy conservaion.

Competitiveness Role. Ensures that workshop energy conservation performance is competitive with other workshops and consistent with overall Railways' goals.

Role in the Social System. Ensures that workshop programmes to maintain and improve energy conservation are supported and communicated to the community and governmental agencies.

Support Role. Ensures that advice and service to the workshop manager, departments and Director, Energy Efficiency is furnished promptly when requested, offered when it is thought to be helpful, is professional in quality, and is supplied in a supportive manner.

Leadership Role. Establishes an active and highly visible energy management programme, to foster and maintain an environment that motivates employees.

Organizing Role. Arranges an energy management programme so that it is effective in support of Railways' overall objectives.

Controlling Role. Ensures that there is a system of reporting of performance against plans and budgets that identifies and communicates variances.

Workshop Energy Management Committee

1. The committee in a small workshop may be formed of representatives from each operating department (site) and function. In a large workshop, it is suggested that the committee be limited to five or six members by having representatives from the engineering, maintenance and production functions, the shift group, and possibly public relations. The committee is chaired by the workshop energy manager/coordinator, and it should meet monthly.

2. The committee assists the workshop energy manager/ coordinator in developing and implementing a workshop energy management programme and an individual operating department (site) programme by:

   a. Instituting programmes and directing efforts to maintain energy awareness throughout the workshop and to solicit active involvement of personnel at all levels.

b. Preparing annual workshop programmes.

c. Reviewing progress of workshop programmes.

d. Forming subcommittees to follow up on specific programme needs as required.

3. The committee serves as a channel of communications for:

   a. Interdepartmental contacts

   b. Relevant committee proceedings and developments back to the workshop personnel.

   c. Feedback between the workshop energy manager/ coordinator and the workshop organization.

4. The committee is a forum for review and generation of ideas:

   a. Presentations by workshop/department coordinators, vendors, consultants, etc.

   b. Acts as a clearinghouse for mutual problems and, where practical, a joint approach to solutions.

   c. Arranges for periodic energy inspections of the plant.

Departmental Energy Management Coordinator

Objective

To develop and maintain an energy conservation programme to provide for the most efficient utilization of the department's energy resources, and to ensure that the departmental programme is consistent with workshop's and Railways' goals.

1. The energy management coordinator develops the department energy conservation objectives, programme, schedules, and budget for the year and secures an approval from the department head. In this function the coordinator organizes the energy-related inputs within the department into a cohesive annual programme.

2. The coordinator develops and maintains a file of departmental energy policy and procedures. The file is updatd as required to remain current with process modification, new, or revised procedures. The file should include at least the following items:

a. Energy conservation opportunities checklist tailored to department operations/requirement.

b. Departmental energy survey data.

c. Formal energy audit.

d. Historical production/energy consumption data and energy use standards for current year.

3. The energy coordinator prepares quarterly departmental energy utilization and conservation status reports and reviews them with the department.

4. The coordinator conducts a continuing energy conservation training and educational/promotional campaign for the department's personnel to create and maintain energy awareness.

   a. Reports pertinent workshop energy management committee proceedings to departmental personnel.

   b. Posts/circulates monthly energy consumption data, quarterly conservation performance, and so on.

5. The coordinator maintains departmental programme records and prepares reports.

   a. Monthly efficiency report (kcal or kJ/kg and/or Rs./kg)

   b. Quarterly reports
   c. Monthly index.
   d. Annual programme and goals.

6. Reviews monthly energy consumption and efficiency against standards. Follows up to explain variations and flags unfavourable trends so that corrective action can be taken.

7. Follows up on conservation opportunities applicable to the department.

8. Serves on the workshop energy management committee and sub-committees that may be required to follow up on specific programmes.

9. Reviews departmental maintenance work orders and notifies the utilities department of revisions affecting unit utility usage.

Energy Management Steering Committee

Objective

To assist in advancing, promoting, and provoking an effective energy management programme for the Indian Railways.

Activities of Committee

1. Provides input for continuing and developing plans to stimulate energy conservation interest, enthusiasm, and awareness for all Railways employees.

2. Brings problems hindering energy conservation efforts to meetings for discussion and possible resolution.

3. Anticipates in obtaining implementation of the energy audit concept.

4. Assists in developing energy management ideas for general application in workshops' programmes.

5. Assists in providing publicity material related to energy conservation for distribution to all workshops and zones.

6. Acts as a sounding board for future programmes and ideas.

9. Assists in developing the overall yearly energy conservation programmes for the Indian Railways.

10. Assists with the annual energy managers/coordinators meeting, if appropriate.

CHAPTER 5

ENERGY AUDIT

CHAPTER 5

ENERGY AUDIT

5.1 INTRODUCTION

Energy is an expensive item in the national budget. In 1985-86, for example, India's expenditure on energy was estimated as approximately Rs. 260 billion. A 10 per cent energy saving would have saved the nation approximately Rs. 26 billion in that year. What would this saving mean to an industry or a commercial organization ? It could mean increased profits, more competitive pricing, and more money available to improve services to public. To the nation, it would mean less investment in energy supply industry, allocation of funds thus released for social programmes and less impact on the environment from energy production and energy use.

A sound energy management programme in any organization would mean monitoring of energy consumption and energy flows at various locations, keeping a record of such measurements, and analyzing the data for improving the energy efficiency. This is in short known as energy audit.

The principles of energy audit in an industrial unit (workshop in the case of Railways) are discussed here with a view to provide an introduction to energy audit.

5.2 WHAT IS AN ENERGY AUDIT ?

Beginning in 1973, energy suddenly became a very important topic. It was elevated to the position of a major topic almost overnight when mass media, politicians, government, business and consumer advocates started talking about it. The need to use energy (especially oil) efficiently was felt more than ever before in 1973-74, after the first oil crisis.

Years before the first oil crisis, professionals realized the importance of cutting down on energy consumption, and developing and utilizing methods of using less energy to produce same or more quantity of any product. The incentive then, as now, was saving money on purchased fuel and electricity. Probably no one would ever know when the term 'energy audit' was coined. The term has certain negative implication and it is not very descriptive. The dictionary meaning of the word 'audit' is 'a formal examination and verification of financial accounts'. This description does not fully convey the meaning of energy audit. Hence, it would probably be better to use an alternative terminology to describe the energy activities mentioned in this Chapter as 'plant energy study'.

However, as the term energy audit has been used for many years by people who speak with authority in energy matters, the expression will stay with us for many more years.

5.3 TYPES OF ENERGY AUDIT

Basically, there are two types of energy audit. They are known as:

(1) Preliminary Scoping Study, and
(2) Detailed Energy Audit

The types of energy audit relate essentially to the scope of energy study, as will be seen below.

Preliminary Scoping Study

The preliminary scoping study (or preliminary energy audit or walk-through energy audit) is used by the professional energy consultant to help define, for himself and for the prospective client, the true dimensions and character of the energy problem at a specific plant. Usually, a qualified consultant visits an industrial unit just for a day. From the data gathered during his visit and his survey of the actual plant, he is able to define the total energy involvement of the plant in energy and monetary terms, and point out areas where energy could be saved with little or no investment. The scoping study includes detailed discussions with plant people regarding past energy consumption trends and energy-saving schemes, as well as the energy management structure both at the plant and corporate levels.

After a few days of analysis of data gethered during the plant visit, the consultant presents the results of the study in a concise report. If he is convinced that significant energy savings would result if a detailed study of the energy consumption in the plant is made, the consultant recommends to the client a detailed energy audit. A proposal for such a service will usually accompany the scoping study report.

The basic objective of a scoping study is to define the energy problem. This can usually be done, most effectively, by an outside energy consultant. However, a

similar technique should be also applied as a first step if meaningful in-house plant energy studies are contemplated.

Energy Bus. An energy bus is a van fitted with computers, measuring instruments, demonstration equipment including video units, and staffed by two engineers. The energy bus is primarily used to carry out on-the-spot energy audits of small- and medium-sized industrial units, and commercial establishments. The purpose of such audits is to propose short-term energy-saving measures. The energy audits would, on the average, take one day per plant.

The concept of energy bus originated in Canada in the late 1970s and was later adopted in 1980 by the European Economic Community. Currently a few energy buses are in operation in India.

Detailed Energy Audit

The detailed energy audit is a thorough analysis and evaluation of all aspects of energy procurement, conversion, distribution and use within a workshop. The effort is intended to define and develop all the significant measures that can be taken within practical limits to improve energy efficiency of the workshop and reduce energy costs. A detailed or complete energy audit transcends traditional arbitrary organizational barriers to realize its full potential. The study can be conducted in-house, provided sufficient expertise is available. If external help is sought, it should never be considered as a substitute for internal effort, but rather as a supplement to the workshop's energy management programme. In many instances, an outside consultant would be able to point out areas for improvement which a workshop personnel would not have noticed due to oversight or neglect.

Quite often, special energy audits are conducted to identify areas for improvement with a narrower scope. These are conducted based on certain priorities assigned by the management as areas requiring special emphasis. Some examples of such audits are: (1) furnaces study, (2) drier audits (3) electrical energy audit (4) lighting audit, and (5) heating and ventilation system study.

The danger with special energy studies, however, is that the area selected for study may not be the real problem, but only part of it. Enormous effort would often be spent in such studies in identifying symptoms rather than the cause of poor energy efficiency. Therefore, it is obvious that special energy audits if required should be pinpointed at the end of a complete energy audit, as part of recommendations.

Energy auditing is a continuing effort to maintain a level of saving and to improve further when opportunities are identified. One cannot rest on past laurels. Unless the momentum is maintained, it would be easy to slip into

lower levels of energy efficiency. Therefore, it is important to continue energy studies in a workshop where a detailed energy audit has been conducted. It is normally recommended that at six-month intervals, an evaluation of progress against the initial recommendations is made; also, new recommendations are developed that have been made viable as a result of changes in energy costs or availability and changes in product-mix or process technology.

Plant energy studies should never be considered on a one-time basis. The successful conduct of detailed energy audit, in itself, is a substantial economic incentive for continued emphasis. It may be necessary to develop internal resources to continue the effort in this regard.

5.4 HOW TO START AN ENERGY AUDIT

Development of a data base is a very valuable activity in the successful conduct of an energy audit. First, an attempt should be made to complete a table similar to Table 1 for fuel and energy used in a workshop for the last financial year.

Table 1

Quantity of Purchased Energy Used and its Cost For the Last Financial Year

Type of Energy	Units	Quantity Used	Mkcal or MJ	Cost per Unit of Energy	Total Cost
Solid fuel	tonne				
Liquid fuel	kL or tonne				
Gaseous fuel	M cu.m				
Electricity	kWh				
Other					
Total					

Having completed the table, one is now aware of what is the cost of energy in the last financial year, how much of it was used in total and by energy forms. A simple step like the one described above should be the beginning of an energy audit programme. The data would further be broken down by areas where energy is consumed, by equipment, by systems, by types of energy, etc. Even an inventory of energy consuming equipment with relevant energy data would be important in an energy audit.

Proformas for furnaces, dryers, and heat loss from equipment/pipe/valves/flanges are given in Appendix. Similar proformas can be developed easily for other equipment/ systems as need arises.

5.5 RESOURCES FOR ENERGY AUDITS

Human Resources. Foremost, adequate qualified and experienced people would be needed for a successful energy audit. In many of the large and medium-sized workshops, an energy manager or an energy engineer/coordinator would be the focal point during the conduct of an energy audit. The energy manager would be responsible for providing the major share of leadership in the workshop's energy conservation effort. It must, however, be remembered that appointing such an energy manager in no way relieves the workshop manager from day-to-day responsibility for the conduct and success of the plant's energy programmes.

Energy is a vital management function and this must be recognized by the top management. The top management is responsible for ensuring that appropriate energy studies are conducted, that the needed resources are provided, and that satisfactory sustained results are achieved.

The other people resources would include supervisors, and plant operators, maintenance mechanics, and others willing and capable to implement and sustain the final end actions that must be taken to save energy. As the worker and the first-line supervisor are closest to the use of energy, it is not unusual for the most productive energy conservation ideas to come from this plant group. Their participation in an energy audit should be encouraged.

Outside energy consultants, equipment vendors, and engineering and design firms would also play a part in energy audit depending on the energy audit requirements and the recommendations stemming from the energy audit.

Instrumentation. Whether an energy audit is done with resources from within a workshop or by an outside consultant, measuring and recording instruments would be needed. Both on-line and portable instruments are required depending on the quantity measured and the type of measurement. Proper and adequate instrumentation is vital for an energy audit, and it speeds the study and improves the accuracy of results. However, inadequate instrumentation should not be an excuse for not conducting an energy audit. Often, experienced workshop personnel, would be able to estimate energy flows from aggregate measured data and design data for equipment and systems in the workshop.

Energy Records. Records of energy consumption, distribution and costs are very useful in the conduct of an energy audit. The more complete, thorough and and accurate the records are, the more useful they become. Records available for at least a full year of normal operation make it possible to evaluate seasonal variations and sustained trends. Here again, a lack of records should not be used as an excuse for deferring an energy study at a workshop. One of the recommendations of good energy audit in such cases is to recommend a set of practical ways of initiating and maintaining a good energy record system.

5.6 CASE STUDY OF AN ENERGY AUDIT

A detailed energy audit was conducted in a medium-sized chemical complex in India producing raw materials for applications ranging from footwear to automobile tyres. The shortage in raw material for the chemical complex, and cheaper and purer intermediate product (of the plant) available from outside the country led to non-operation of one of the units of the plant, which resulted in a mismatch of the plant's steam-electricity balance and a large wastage of steam. This coupled with escalating fuel costs and fuel bills made it essential that the organization review the energy situation in the chemical complex.

To analyze energy use patterns, and to investigate and report on energy conservation measures, the company employed an outside energy consultant to conduct an energy audit.

The energy audit was divided into a few basic tasks, which addressed mainly the steam and electricity consumption. Being a unit having captive-generated power, the steam-electricity balance was critical to the plant's energy efficiency and hence, it was analyzed in detail.

The detailed energy audit required roughly four months of intensive effort preceded by a preliminary energy audit and data collection. After the preliminary analysis, an interim report was issued. Technical feasibility of the provisional conservation measures listed in the report was discussed with the plant personnel. After the technical feasibility was ascertained, economic analyses were performed for all those measures that were finally recommended for implementation. At the end of the plant energy study, a final report was issued to the plant management.

The production, design and energy-related data required for the study were supplied by the plant personnel. Approximately 60 per cent of the energy flow data supplied was based on actual measurement. The rest were from estimation and design data of various systems and equipment.

Some of the important recommendations of the study included the following:

1. Installation of an extraction-condensing turbine

2. Replacement of an induced-draft (ID) fan (steam) turbine drive with an electric-motor drive

3. Replacement of steam-driven plant air compressors by electric motor-driven compressors of reciprocating type

4. Replacement of existing dowtherm furnace by a smaller capacity heater

5. A structured formal energy management team

6. Housekeeping measures including steam trap maintenance, hot and cold pipe insulation and tighter process and combustion control

7. Additional instrumentation for monitoring energy flows

8. Use of standard proformas developed by the consultant

9. Analysis of energy-related data on a microcomputer and periodical presentation of relevant data to the top management

Many of the energy-saving schemes recommended had payback periods of less than a year. Even the major schemes had payback periods of less than three years. In the report, the energy-saving options were prioritized based on the company's investment potential and future plans.

5.7 CONCLUSION

Energy audit is a vital element in the entire energy management programme, which includes many managerial and operational activities and responsibilities. The energy audit process is essential to the implementation of a successful energy conservation programme in any of the Railway workshops.

An energy audit is not an end in itself. It does not save energy; it merely indicates areas with the greatest potential for energy (and monetary) savings, and therefore, areas where further actions needs to be concentrated. It also provides a starting point or a baseline from which progress on energy conservation can be measured.

If an external consultant is appointed for energy audit, an intense interaction between workshop personnel and the study team is essential for a proper understanding and a meaningful analysis of the plant's energy options. Without the active participation at all levels, savings in energy use cannot be expected and accomplished.

Projects

1. Conduct a walk-through energy audit in your workshop, and identify areas of large energy consumption and energy savings.

2. Identify both static and portable instruments (for electrical energy and thermal energy) for your workshop, and provide justification for installing them.

3. Develop specific proformas for large energy-using systems/equipment in your workshop.

4. Develop proformas for overall energy consumption in your workshop both at aggregate and disaggregate levels.

5. Develop methodology for computing efficiencies of various systems/equipment.

APPENDIX

PROFORMA FOR CONDUCTING ENERGY AUDITS

PROFORMA 1

Furnaces

Furnace Details :

Furnace		1	2	3
Location	:			
Manufacturer	:			
Age (years)	:			
Type	:			
Stock material type	:			
Throughput rating (kg/hr)	:			
Normal operating pressure (neg. in W.G.)	:			
Type of heating system	:			
Burner(s)	:			
Number	:			
Fuel(s) fired	:			
Manufacturer	:			
Age (years)	:			
Type	:			
Burner controls	:			

Furnace Evaluation Checklist:

Item	Equipment	Comments
Physical appearance	Furnace Burners Fuel system Atmosphere control system	
External structure	Furnace walls Doors	
Safety equipment & instrumentation	Furnace Burner Fuel system Atmosphere control system	
Valves, fittings and insulation	Burners Fuel system Distribution	
Product quality		

Furnace Energy Audit Data Collection Form

Date :

Time :

Location :

Fuel Type :

Item	Units	Test 1	Test 2	Test 3
Flue gas analysis				
% CO_2	%			
% CO_2	%			
% CO_2	%			
Flue gas temperature	^oC			
Ambient temperature	^oC			
Flue gas flow rate	^oC			
Flue gas flow rate	m^3/min			

Item	Units	Test 1	Test 2	Test 3
Wall material emissivity				
Inside wall temperature	^oC			
Outside wall temperature	^oC			
Feed material temperatures	^oC			
- in				
- out				
Stock throughput				
Stock emissivity				
Furnace wall				
- material				
- Thickness				
- Construction details				
Furnace and Door dimensions				

PROFORMA 2

Dryer Details

Dryer	:			
Dryer No.	:	1	2	3
Manufacturer	:			
Age (years)	:			
Type (direct/ indirect)	:			
Material dried	:			
Throughput (specity units)	:			

Dryer No.		1	2	3
Drying medium	:			
Normal operating temperature (^{o}C)	:			
Moisture content - in (%) - out (%)	:			
Burners or cylinders	:			
Manufacturer	:			
Number	:			
Age	:			
Type	:			
Fuel/heating medium	:			
Draft control	:			

Dryer Test Data

Dryer No.	:			
Fuel (name)	:			
Fuel flow metered (Yes/No)	:			
Fuel flow rate (kg/h or L/h)	:			
Estimated calorific value (kJ/kg)	:			
Thermic fluid (Yes/No)	:			
Total heat input from thermic fluid (kcal/h)	:			
Material in Temperature (^{o}C)	:			
Material out Temperature (^{o}C)	:			
Fresh air relative humidity (%)	:			
Dryer operating temperature (^{o}C)	:			

Dryer No.		1	2	3
Fuel input (kg/h)	:			
Dryer air temperature (^{o}C)	:			
Dryer total volume (m^3)	:			
Exhaust air dry bulb/ wet bulb temperature (^{o}C)	:			
Exhaust air humidity (%)	:			
Exhaust air flow rate (m^3/h)	:			

PROFORMA 3

Surface Heat Loss

Equipment

Ambient temperature (^{o}C)

Equipment No.	Type of equipment	Inside temperature (^{o}C)	Identification of surface being examined

Characteristics of Surface			Surface Temperature (°C)	Surrounding Air Velocity (m/sec)
Material	Condition	Colour		

Pipe/Valve/Flange

Ambient temperature = (°C)

Location	Size (mm)	Annual hours of operation	Bare or insulated	Type of insulation and its jacket

Condition of Insulation	Surface Temperature (°C)	Additional Information/Remarks

CHAPTER 6

ENERGY CONSERVATION TECHNOLOGIES AND MEASURES

CHAPTER 6

Section 1: Energy Conservation Concepts
Section 2: Industrial Furnaces
Section 3: Fluidized-Bed Furnaces
Section 4: Energy Efficient Burners
Section 5: Waste Heat Recovery and Utilization
Section 6: Heat Pump
Section 7: Diesel Generators
Section 8: Compressed Air System
Section 9: Insulation
Section 10: Electrical Energy Conservation
Section 11: Instrumentation

CHAPTER 6

Section 1: Energy Conservation Concepts

6.1.1 Introduction

Most industrial processes evolved in an era where energy was abundant and cheap. The oil shocks of the seventies have led to a drastic rethinking on energy. Spiralling energy prices have resulted in a greater emphasis on energy conservation. In this section, some of the basic concepts of energy conservation are presented.

6.1.2 Thermal Energy: The Laws of Thermodynamics Revisited

The first law - an energy balance

The first priority in energy conservation in a plant is to account for various energy flows in different plant areas.

An energy balance is based on the first law of thermodynamics. The first step of drawing up an energy balance is done with the help of a process flowsheet and identification of material flows in the system. Energy contents can be assigned to various streams and the energy input and output for different pieces of equipment can be obtained. The losses or leaks from the system can be identified as the difference between the input energy and the energy output. The pictorial representation of energy flows in the system is made in a Sankey diagram.

Consider a simple condensing steam power plant as shown in Figure 1.

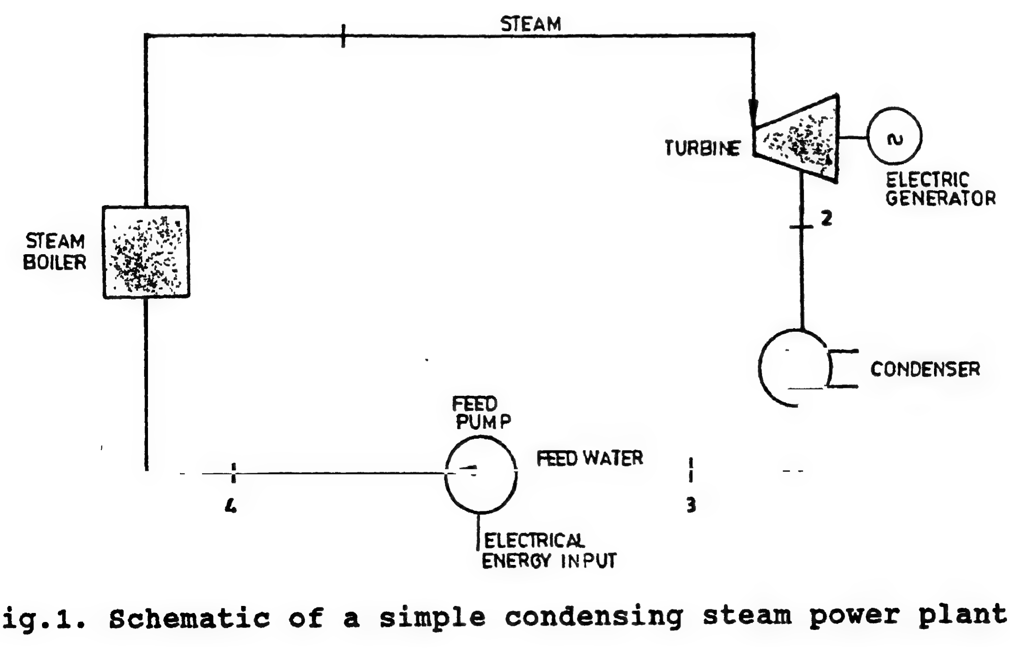

Fig.1. Schematic of a simple condensing steam power plant.

Neglecting the power consumption for the water feed pump, an energy balance for a typical condensing steam power plant is shown in Figure 2.

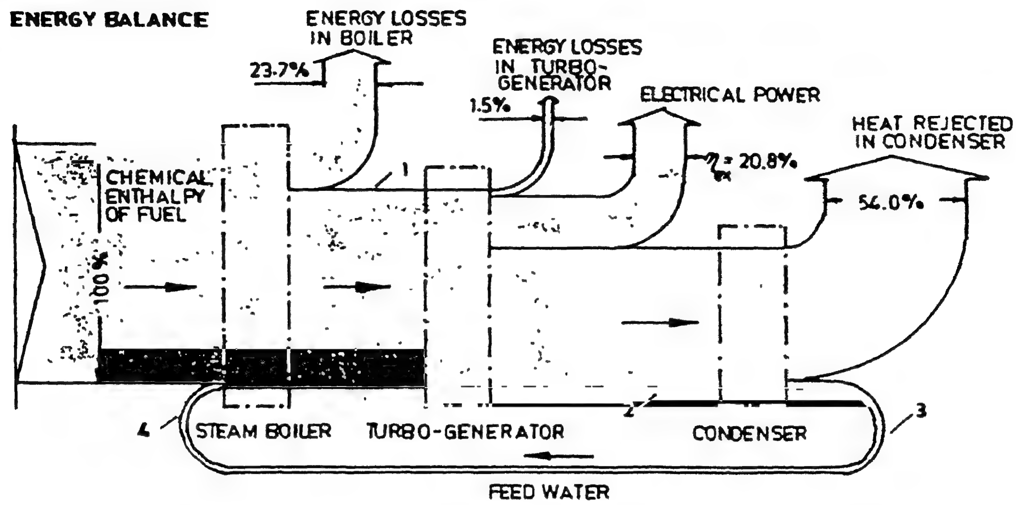

Fig. 2: Sankey diagram for steam power plant

Of the 100 per cent input chemical enthalpy, 23.7 per cent is lost in the boiler, 54 per cent is lost as heat rejected in the condenser and 1.5 per cent is lost in the turbo-generator. Of the total energy input, 20.8 per cent is available as electrical power output. From the energy balance it appears that the major portion of the losses (54 per cent) occurs due to the heat rejected in the condenser. An energy balance can quantify the heat leaks from the system and the energy lost with the effluents. It should be noted that energy balances do not account for differences in the quality of energy.

6.1.3 The Second Law of Thermodynamics - An Exergy Balance

An energy balance merely quantifies the losses due to heat leaks from the system or due to the heat lost with the waste streams. It does not give any information about the irreversibility of the process. Thus throttling or heat exchange may appear to be a 100 per cent efficient process as no enthalpy is lost from the system, whereas from the consideration of work that could be done by the system, it is inefficient.

In order to analyse process irreversibilities it is essential to rely on the second law of thermodynamics. The second law constrains the direction in which any energy transformation can occur.

The second law of thermodynamics can be presented in the form of an exergy balance where the difference between the exergy input to the system and the exergy output is the lost work due to irreversibility. **The exergy of a substance is the maximum useful work which can be obtained from the system by interacting it with the environment.** The specific exergy of a stream of matter (in the absence of nuclear effects, magnetism, electricity and surface tension) is given by:

$$ex = \frac{MV^2}{2} + Mg\,(Z-Z_o) + (h - h_o) - T_o\,(s - s_o) + e_{ch} \quad ..(1)$$

where M is the molecular weight

V is the velocity

Z, Z_o are the height and reference height

s, s_o are the specific entropy and reference entropy

h, h_o are the specific enthalpy and reference enthalpy

T_o is the reference ambient temperature

g is acceleration due to gravity

e_{ch} specific chemical exergy

An exergy balance can pinpoint the irreversibilities in different process equipment. The exergetic efficiency of a process can be computed as the ratio of the useful exergy output from the process to the exergy input.

Another useful performance index is obtained by the comparison of the actual exergy consumption in the process to the minimum exergy required for the specified task.

A Grassman diagram shows the exergy flows within a system and quantifies the irreversibilities or losses in different process equipment. The exergy balance helps in identifying the scope for savings.

The Grassmann diagram for the simple condensing steam power plant shown in Figure 1 is presented in Figure 3. It is seen that 68.3 per cent of the input exergy is lost due to irreversibility in the boiler. The work lost due to condenser accounts for 3.8 per cent of the input exergy while the turbo-generator losses account for 7.7 per cent of the input exergy. 20.2 per cent of the input exergy is available as useful electrical work output.

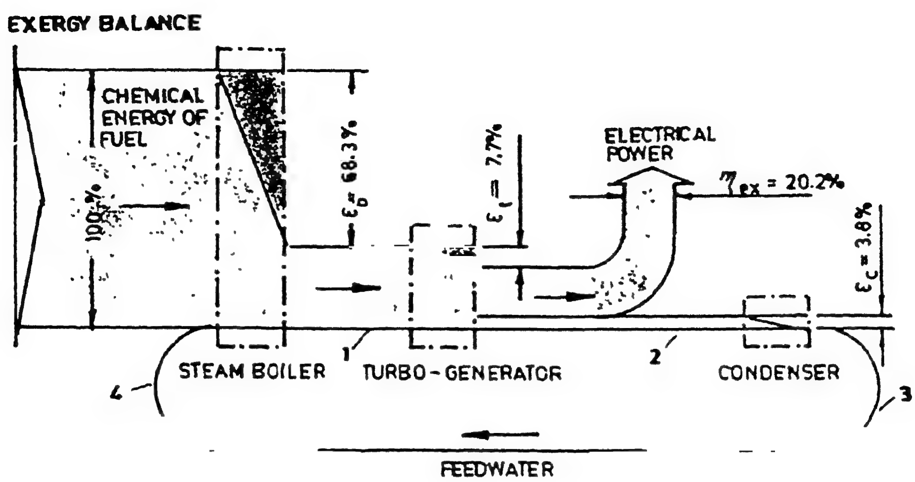

Fig. 3: Grassman diagram for steam power plant

After making an exergy analysis and quantifying component irreversibilities, it is necessary to estimate the unavoidable irreversibility. By adding the unavoidable irreversibility to the minimum work requirement, a realistic target for exergy requirement of a process can be established. The interpretation of the results of an exergy analysis would often require the intuition and experience of practising engineers.

An exergy analysis provides additional information (along with an energy balance) and can form the basis for rational energy conservation programme.

It is possible to devise optimization strategies for minimising the overall system irreversibility and design a matching control system. Optimal operation may involve cascading of heat, cogeneration, and utilisation of waste heat. The concept of heat exchanger networking is also derived from the laws of thermodynamics.

Electrical Energy

The electrical energy conservation concepts are described in Chapter 6, section 10.

PROJECTS

1. Draw a Sankey diagram for an energy-intensive system/equipment in your plant/workshop after determining various losses.

2. Draw a Grassman diagram for a boiler/turbine system or diesel generator in your plant/workshop. Define methods of increasing the overall output (efficiency) of the boiler/turbine system or diesel generator.

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Section 2: Industrial Furnaces

6.2.1 Introduction

Furnaces play an important part in modern industry. Almost every manufactured article requires heat at some stage of production, and well-designed and efficiently-operated furnaces can have a significant effect on cost, output and quality.

The term "industrial furnaces," as used in this Section includes only those furnaces in which heat is imparted for the purpose of raising temperature and in which no chemical changes, or changes of state such as melting or vaporization take place. Such furnaces might be called "metal-heating furnaces". In metal working, temperature plays an extremely important role. High temperature softens all metals and renders most of them fit for forming operations like bending, forging, pressing, extrusion, and rolling. Further heating above this range may melt metals depending upon their melting point. High temperature also takes strain out of metals; the process of heating metals for this purpose and then cooling in such a manner that no new strains are developed is known as annealing. Metals are also heated for the purpose of absorbing carbon, as in case hardening, or for the purpose of changing the state of carbon alloys, as in the annealing of malleable castings.

6.2.2 General Description and Classification of Industrial Furnaces

The required temperature in furnaces is produced by the generation of heat. Two methods are employed:

1. Combustion of fuel.
2. Conversion of electric energy into heat.

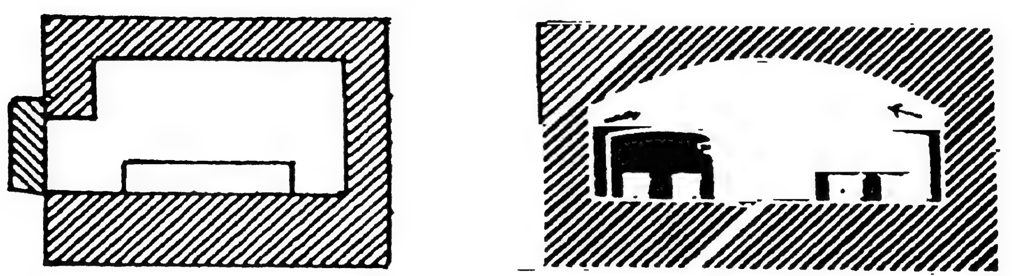

Fig.1: Batch type, or "in-and-out" type of furnace

The combustion type of furnaces is used to a much greater extent than the electric type; however, for many purposes, the electric type is preferred, because it offers advantages that cannot be measured in terms of fuel cost alone.

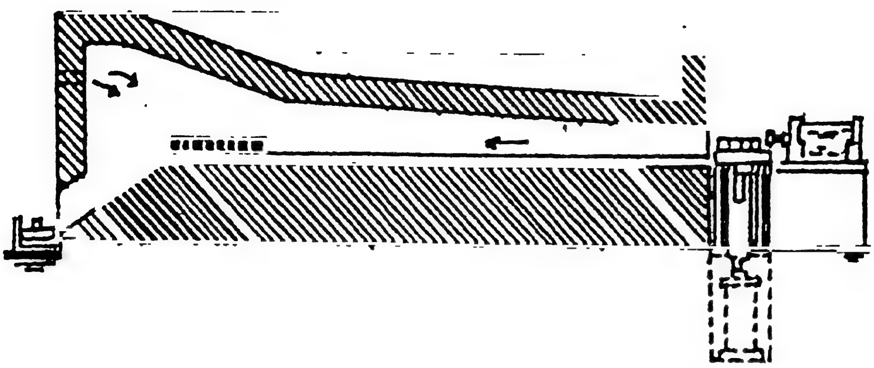

Fig.2: Continuous furnace with end discharge

Another classification is based on the handling of the material in its passage through the furnace. Two principal types of furnace are:

1. The in-and-out furnace, or "batch" type, or "intermittent" or periodic furnace.

2. The continuous furnace.

These types are illustrated in Fig. 1, 2, and 3. In the in-and-out furnace the temperature is practically constant throughout the interior. The stock to be heated is laid in a certain position and remains there until it is heated to the desired temperature. It is then removed, generally through the door by which it entered.

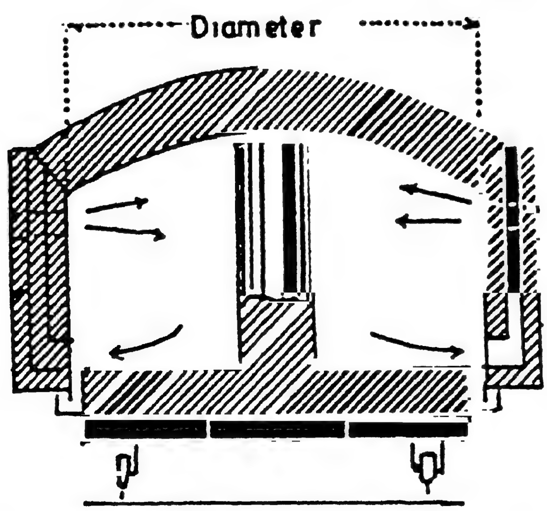

Fig. 3: Continuous furnace with rotating hearth

In the continuous furnace, the charged material, or stock, moves while it is being heated. The straight-line type (Fig. 2) is very common. Either the material passes over a stationary hearth, or else the hearth itself moves. When the stationary hearth is employed, the material passes over skids or rolls, being carried down an incline by the force of gravity, or is pushed through the furnace by mechanical pushers. Figure 2 illustrates a continuous furnace with "end discharge".

For many purposes the rotating-hearth or rotating-table furnace (Fig. 3) is very useful. The stock is placed on the hearth, and is removed after the table has almost completed a revolution. The car-type furnace, illustrated in Fig. 4, has a movable hearth, which, however, is stationary during the heating period, and sometimes also during the cooling period. The car is moved to a position outside the furnace for loading and unloading. The furnace is mainly used for heating heavy or bulky material.

In furnaces that are heated by the combustion of fuel, many differences exist because of the nature of fuel. A small number of industrial furnaces are fired by powdered coal.

The place where combustion takes place and the manner of directing the products of combustion serve as an additional basis of classification. If the flames are developed in the heating chamber properly, as in Fig. 1 or in Fig. 3, furnace is said to be direct-fired. It is sometimes called the oven-type or box-type furnace.

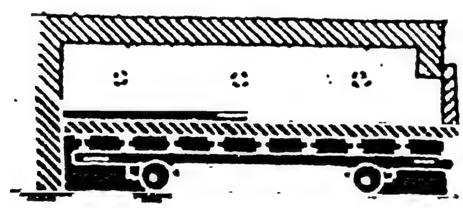

Fig.4: Car-bottom type of furnace

If the flame is produced under the hearth (Fig. 5) and then sweeps up into the heating chamber, the furnace is said to be "underfired". If the flame is developed in a combustion chamber at one side of the heating chamber and then passes over a bridge wall into the heating chamber (Fig. 6) the furnace is said to be "sidefired". Finally, if the flame is developed in a space above the

heating chamber (Fig. 7) and spreads into it through a perforated arch, the furnace is said to be "overfired". The term "reverberatory furnace" means the type of furnace in which flame is developed at some distance above the hearth and is then deflected onto the hearth by an arched or sloped roof. The term "reverberatory furnace" is common in the metal-smelting industry, but is not used in connection with other industrial furnaces.

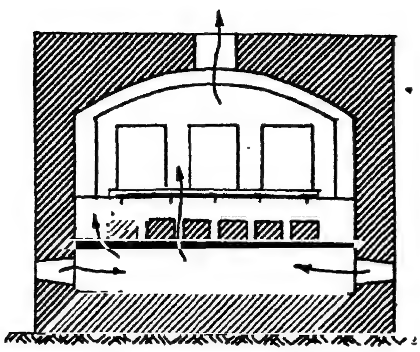

Fig.5: Underfired furnace

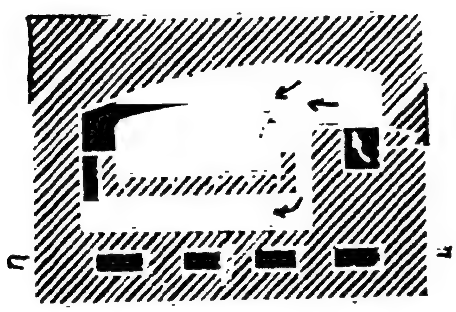

Fig.6: Sidefired furnace

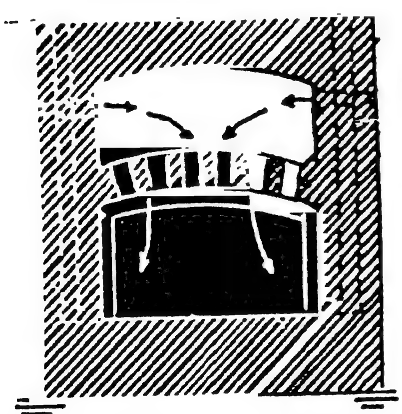

Fig.7: Overfired furnace

For medium or low temperatures, the recirculation furnace or furnace with forced circulation is preferred, if uniformity of temperature is to be attained (Fig. 8).

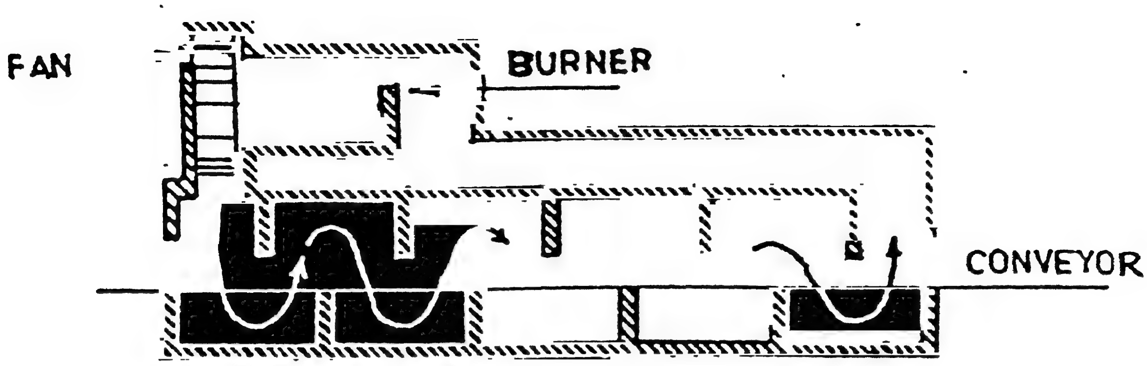

Fig.8: Recirculating furnace

In all these types, the products of combustion come in contact with the stock which is to be heated. For certain processes such contact is injurious to the material being heated; in such cases the stock or charge is sometimes enclosed in a muffle which, as a rule, is heated by products of combustion. A muffle furnace is sketched in Fig. 9; the muffle is indicated by the closed, solid, heavy line. Not only is the charge (in this case a pile of sheets enclosed in a muffle), but the products of combustion also pass through muffles, which are called radiant tubes. Many furnaces require a special atmosphere for protection of the stock from oxidation or decarburization, or for other purposes, and are built with a gas-tight outer casing surrounding the refractory lining. Heat is supplied by fuel-fired radiant tubes or by electric resistance elements.

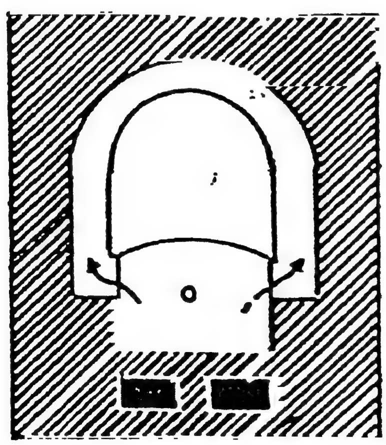

Fig.9: Muffle furnace

If protection against high temperature is more of an objective than protection from furnace atmosphere, the roof of the muffle is omitted and the furnace bears the name "semi-muffle furnace". In a sense, pot furnaces are 'no-roof' furnaces, because there is no roof on the muffle. A pot furnace is illustrated in Fig. 10.

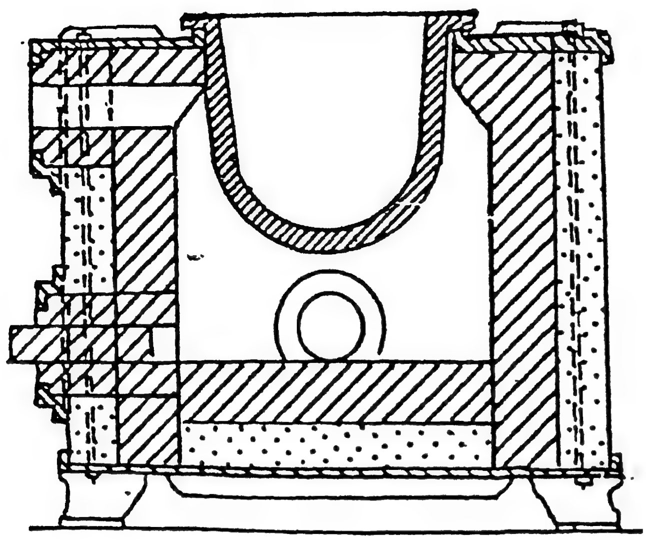

Fig.10: Pot furnace

Preheating of the combustion air is accomplished by two distinctly different methods. In one method (Fig. 11), the outgoing flue gases transfer a part of their heat to the incoming air, in a steady flow through a wall. This heat exchanger is called a "recuperator", and the furnace is said to be of the recuperative type. In another

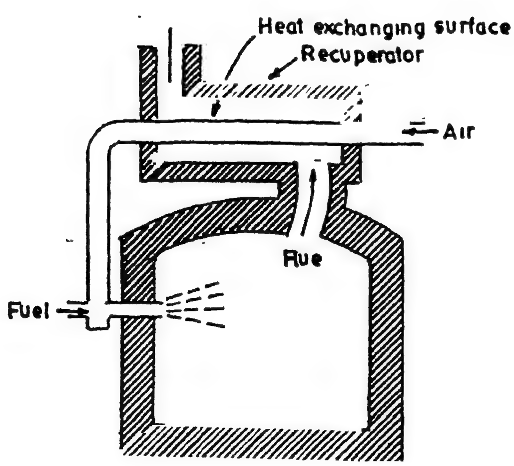

Fig.11: Recuperative furnace

type, the outgoing products of combustion impart heat to brickwork or to metal placed in a heat-exchanger chamber, while the incoming air absorbs heat from the brickwork or plates of another heat-exchanger chamber, which had previously been heated up by the flue gases (Fig. 12). The direction of the flame is reversed at regular intervals. This furnace is said to be of the regenerative type; it is also called a "Siemens" furnace having been invented by Sir William Siemens and Friedrich Siemens.

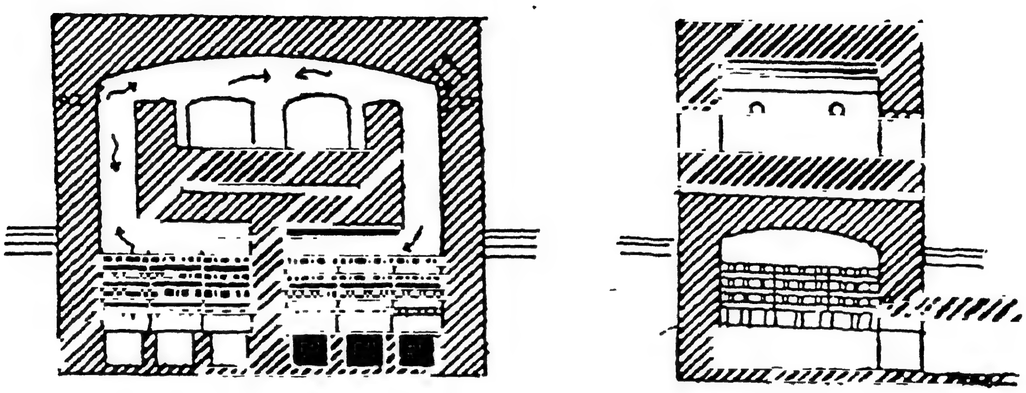

Fig.12: Regenerative furnace

There are stationary furnaces and portable furnaces; there are also many forms of "automatic furnaces", in which the stock is carried through the heating chamber by a conveying mechanism. A furnace with a chain conveyor is illustrated in Fig. 13. Other forms of conveyors are wire belts, rocker bars, and rollers. Figure 14 illustrates a furnace with conveyor rolls.

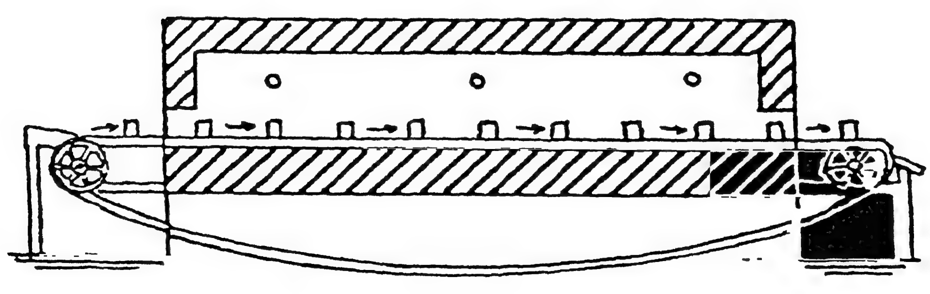

Fig.13: Chain conveyor furnace

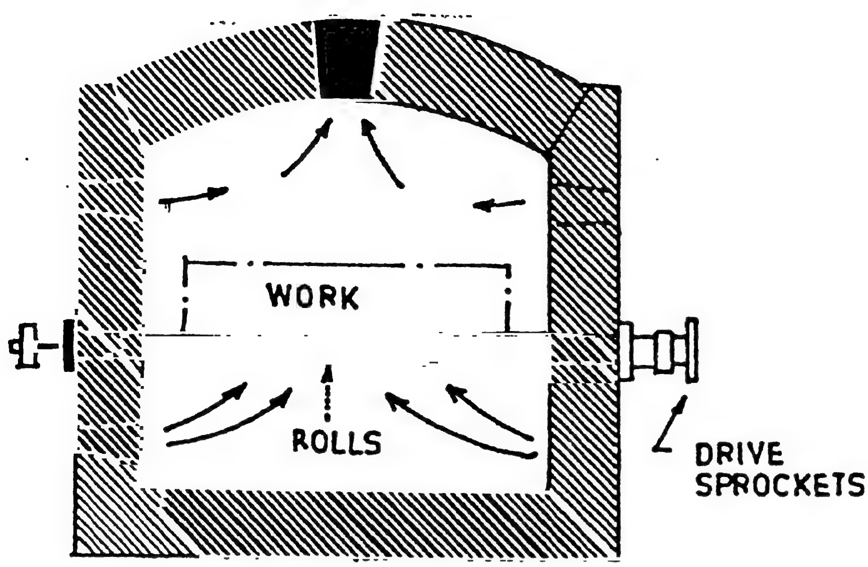

Fig.14: Roller hearth furnace

A large number of furnaces are heated by conversion of electric energy into heat. This conversion may be effected by one or more arcs, by primary or induced currents flowing through resistors, or by currents inducted in the charge itself. Although most electrically heated industrial furnaces are of the resistor type, the induction type is preferred for some purposes.

Another furnace for burning coal, the cyclone furnace, has been developed and is now widely used. The cyclone furnace is applicable to coals having a slag viscosity of 250 poise at 1425^{o}C or lower, provided the ash analysis does not indicate excessive formation of iron or iron pyrite. With these coals, cyclone furnace firing provides the benefits besides the ones obtainable with pulverized coal firing.

1. Reduction in fly ash content in the flue gas.

2. Saving in the cost of fuel preparation, since only crushing is required instead of pulverization.

3. Reduction in furnace size.

Principle of operation: The cyclone furnace (Fig. 15) is a water-cooled horizontal cylinder in which fuel is fired accompanied by release of heat at extremely high rates, and thus combustion is completed. Its water-cooled surfaces are studded, and covered with refractory over

most of their area. Coal crushed in a simple crusher, so that approximately 95 per cent of it will pass a 4-mesh screen, is introduced into the burner end of the cyclone. About 20 per cent of the combustion air, termed as primary air, also enters the burner tangentially and imparts a whirling motion to the incoming coal. Secondary air with a velocity of approximately 90 m/s is admitted in the same direction tangentially at the roof of the main barrel of the cyclone and imparts a further whirling or centrifugal action to the coal particles. A small amount of air (up to about 5 per cent) is admitted at the center of the burner. This is known as the "tertiary" air (Fig. 15).

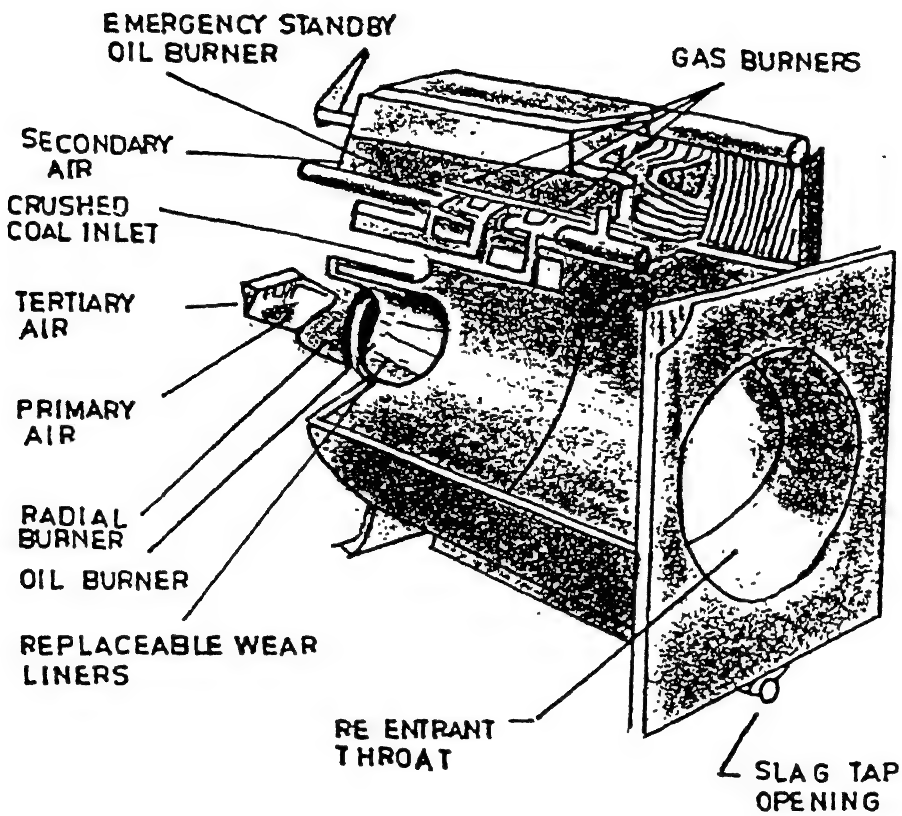

Fig.15: The cyclone furnace, in the form of a horizontal cylinder, is completely water cooled by connection to the main boiler circulation. All combustion gases leave through the re-entrant throat at the rear. Molten slag drains from the bottom at the rear through a small opening into the adjacent boiler furnace.

Suitability of Fuels for the Cyclone Furnace. The Cyclone Furnace is capable of burning successfully a large variety of fuels. A wide range of coals varying in rank from low volatile bituminous to lignite may be successfully burned, and in addition other solid fuels such as wood, bark, coal chars, refuse, and petroleum coke may be satisfactorily fired in combinations with other fossil fuels. Fuel oils and gases are also suitable for firing.

The suitability of coals is dependent on the moisture, ash and volatile contents of the coal together with the chemical composition of the ash. The volatile matter should be higher than 15 per cent, on a dry basis, to obtain the required high combustion rate. The ash content should be a minimum of about 6 per cent to provide a proper slag coating in the cyclone and can be as high as 25 per cent on a dry basis. A wide range of moisture content is permissible depending on coal rank, secondary air temperature and fuel preparation equipment that may include capability for pre-drying the fuel. Since the Indian coals do not conform to the above requirements, cyclone furnaces are not commonly used in India.

6.2.3 Modern Methods of Steel Manufacture(1)

Modern mass production methods of steel manufacture began in 1856 when Henry Bessemer attempted to speed up wrought-iron manufacture by blowing air through a charge of molten pig iron contained in a pear-shaped 'converter'. Of the air blown into the Bessemer converter only 20 per cent by volume was utilised in oxidising the impurities. This of course was by oxygen in air. The remaining 80 per cent (mainly nitrogen) entered the converter cold and emerged as hot gas, thus carrying heat away from the converter and reducing the thermal efficiency of the process. Moreover, small amounts of nitrogen dissolved in steel during the 'blow'. This increased the hardness of the product and frustrated the efforts to satisfy the demand for mild steel of increasing ductility by the motor car manufacturers and others.

In 1952, a new approach to these problems was made in steel plants by Linz and Donnawitz in Austria. Here, instead of blowing air through molten pig iron as in the Bessemer process, pure oxygen was injected into the surface of molten pig iron via a water-cooled 'lance'. This process called the L-D process - was made possible by the introduction of cheap tonnage oxygen.

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(1) Though steelmaking processes are not relevant to Railway's workshops, sections on steelmaking furnaces are included for illustrating applications of special types of furnaces.

6.2.4 Basic Oxygen Steelmaking

Following the introduction of L-D steelmaking in 1952, a spate of modifications of the process followed. Thus both the Kaldo process (Sweden) and the Rotor process (West Germany) were popular for a time and it is inevitable that variations of the general oxygen method will continue to be developed. All such modifications have the following features in common.

(i) an oxygen blast is used to oxidise impurities in the original raw material, these oxidised impurities being drawn off in the slag;

(ii) the processes are chemically basic so that phosphorus removal is effective.

A basic oxygen furnace (B.O.F.) is a pear-shaped vessel of up to 400 tonnes capacity, lined with magnesite bricks covered with a layer of dolomite. Scrap is first loaded into the converter followed by the charge of molten pig iron. Oxygen is then blown at the surface of the molten charge through a water-cooled lance which is lowered through the mouth of the converter (Fig. 16).

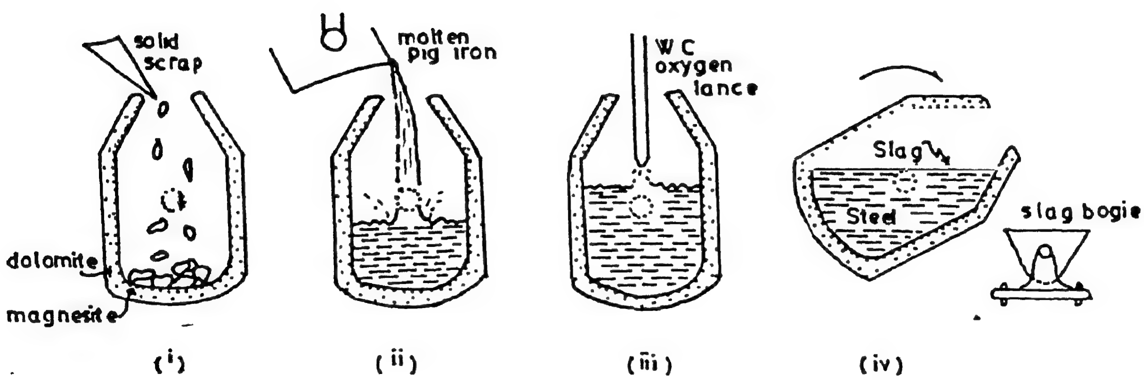

Fig.16: Stages in the manufacture of steel in a B.O.F. The water-cooled oxygen lance may be up to 0.5 m in diameter and its tip between 1 and 3 m above the surface of the charge - depending upon the composition of the latter.

As soon as the oxidising reaction commences, lime, fluorspar and millscale are added to the converter to produce a slag on the surface which will collect the impurities oxidised from the charge. At the end of the 'blow', the slag is run off first and the charge of steel is then transferred to a ladle for casting as ingots.

B.O.F. has the following major advantages over competing processes:

(i) It is rapid - the cycling time is about forty five minutes;

(ii) Nitrogen contamination is very low so that deep-drawing-quality mild steel is produced;

(iii) Thermal efficiency is high because heat is not carried away by nitrogen as in the former Bessemer process. Hence, the charge may include 40 per cent and in some circumstances 50 per cent scrap;

(iv) A wide variety of both scrap and pig iron can be used.

Oxygen lancing of molten steel in open hearth (OH) furnaces as a process of intensification to increase productivity and reduce energy consumption is a well established practice. Encouraged by the large energy saving potential of KORF process which involves submerged oxygen injection in OH processes, Tata Steel entered in to an agreement with KOTEC AG, Switzerland, to acquire the knowhow of KORF technology. Work on implementation in two of the eight OH furnaces was completed in mid 1987. The benefits in terms of energy savings are as follows:

- The average fuel rate in OH furnaces decreased from 725 kcal/kg to 315 kcal/kg crude steel.

- Total heat working time will be 4 hours and 35 minutes instead of 9 hours and 30 minutes.

- Reduction in oxygen consumption by about 8 m^3/t crude steel.

- Extra generation of 152 t/day of steam from the waste heat.

Fig.17 displays the energy conservation potential of OH furnaces with the application of KORF technology.

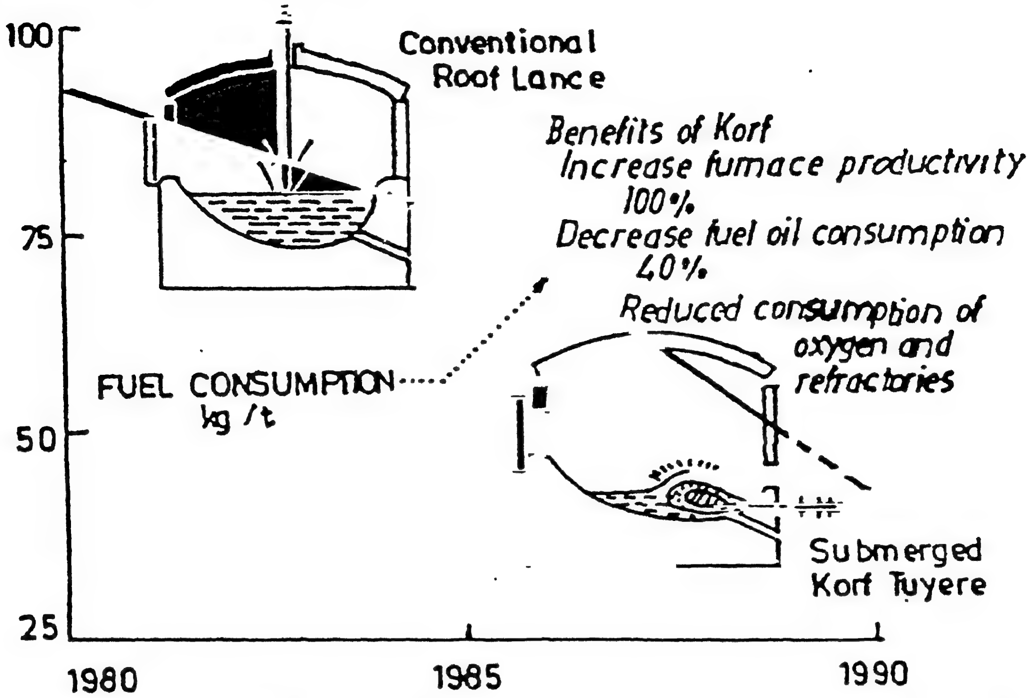

Fig. 17: KORF technology for efficient fuel and oxygenutilization in open hearth furnaces

6.2.5 Energy Conservation in Furnaces

The following sections describe the areas where losses in furnaces occur and the ways of reducing them.

6.2.5.1 Furnace Loading

One of the most vital factors affecting efficiency of a furnace is its loading. There is a particular loading at which a furnace will operate at maximum thermal efficiency. If the furnace is underloaded, a smaller fraction of the available heat in the working chamber will be taken up by the load and therefore, efficiency will be low.

The best method of loading is generally obtained by trial - noting the weight of material put in at each charge, the time taken to reach particular temperature and the amount of fuel used. Every endeavour should be made to load a furnace at the rate associated with optimum efficiency although it must be realised that limitations to achieve this are sometimes imposed by work availability or some other factors beyond control.

The "no load" consumption to maintain a simple batch type furnace at 1300°C when empty is about 70 per cent of that required to operate at optimum loading rate.

Table 1 indicates the effect of increased loading rates on the thermal efficiency and performance of a continuous reheating furnace. Table 2 shows typical hearth loading rates normally expected in good practice.

Table 1

Effect of Loading on a Continuous Furnace Performance

Production Rate	tonnes/hr Units	10.0	5.0	3.0	1.0
Heat to Stack	MJ	7385.0	3692.0	2215.0	738.0
Waste gas Loss	MJ	10550.0	7385.0	6330.0	5412.0
Structural Loss, etc.	MJ	7385.0	7385.0	7385.0	7385.0
Total Heat Input	MJ	25320.0	18462.0	15930.0	13535.0
	MJ/t	2532.0	3692.4	5310.0	13535.0

Table 2

Typical Hearth Loading Rates Expected in Good Practice

	$kg/m^2.h$
Heat treatment furnace	147-195
Annealing furnace	195-293
Drop stamping and forging	293-390
Continuous reheating	342-489

6.2.5.2 Placing of Stock

The disposition of the load on the furnace hearth should be arranged so that

(a) it receives the maximum amount of radiation from the hot surfaces of the heating chamber and the flames produced.

(b) the hot gases are efficiently circulated around the heat receiving surfaces.

Stock should not be placed in the following positions:

(a) in the direct path of the burners or where flame impingement is likely to occur.

(b) in an area which is likely to cause a blockage or restriction of the flue system of the furnace.

(c) close to any door openings where cold spots are likely to develop.

6.2.5.3 Load Residence Time

In the interests of economy and product quality, the materials comprising the load should only remain in the furnace for the minimum time to obtain the required physical and metallurgical requirements. When the materials attain these properties they should be removed from the furnace to avoid any damage and fuel wastage. The higher the working temperature the higher the loss per unit time.

The effect on the materials by excessive residence time will be an increase in surface defects due to oxidation. The rate of such oxidation is dependent upon time, temperature, as well as free oxygen content.

This possible increase in surface defects can lead to rejection of the product or expensive secondary surface fini-shing techniques such as turning, grinding, polish-ing, etc.

6.2.5.3 Heat Losses from Furnace

Refer to Fig. 18 for a clear understanding of the distribution of heat in a simple furnace. Most of the heat is released in the combustion zone at the left and travels from there to the right. The passage of heat into the stock, as indicated by arrows 1, is desired. But heat also goes elsewhere; some of it passes into the furnace walls and some into the hearth, as indicated by arrows 3, increasing the temperature of those parts. Another portion of the heat is lost to the surroundings by radiation and convection from the outer surface of the walls or by conduction into the ground (see arrows 2). Through cracks or other openings, heat radiates away, 4; and furnace gases pass out around the door, 5: frequently burning in the open and carrying off heat. Heat is lost every time a door is opened. Water cooling of skid pipes and of conveyor rollers absorbs

large quantities of heat and lowers thermal efficiency. If the charge is heated in containers or on travelling chains a large part of the heat is dissipated in the open by these devices. Finally, heat passes out with the products of combustion 7, in the form of sensible heat, and heat of combustibles escaping unburned (incomplete combustion).

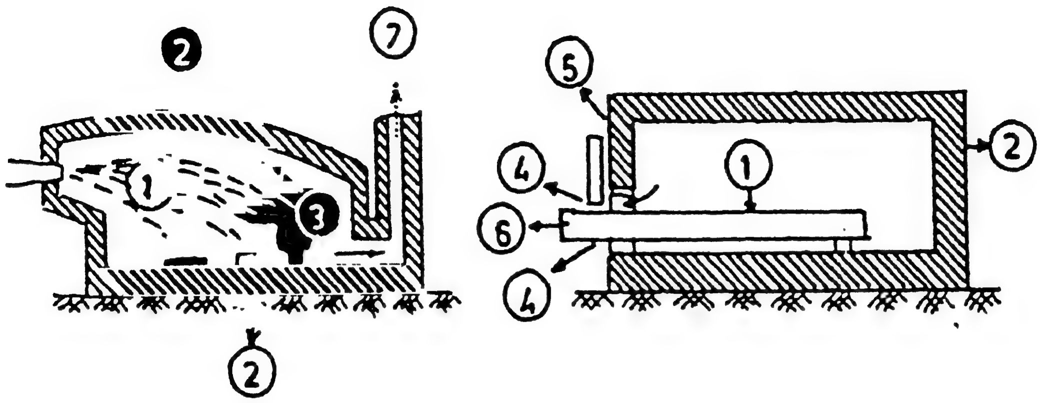

Fig.18: Flow of heat in a furnace

Fuel economy demands that the fraction of the total heat that passes into the stock be as large as is compatible with correct heating. The attainment of this figure requires, determination of the heat losses and the methods of reducing them.

(a) Heat Lost from Furnace Walls (Wall Loss)

The heat lost from the outer surfaces of outside of furnace walls is one of the salient features affecting the economy of furnaces. The wall loss during continued, uninterrupted operation of a furnace differs from the wall loss of the same furnace if it is operated intermittently.

For steady heat flow through a wall, the conditions indicated in Fig. 19 are used. The temperature of the wall drops steadily towards its outer surface, where the temperature exceeds that of the surrounding air. The heat loss for a given extent of wall and for a given furnace temperature becomes less if the wall is made thicker, or if the wall is made of a better insulator, or if the outer wall surface is of such a character that it does not readily give up its heat to the surrounding media.

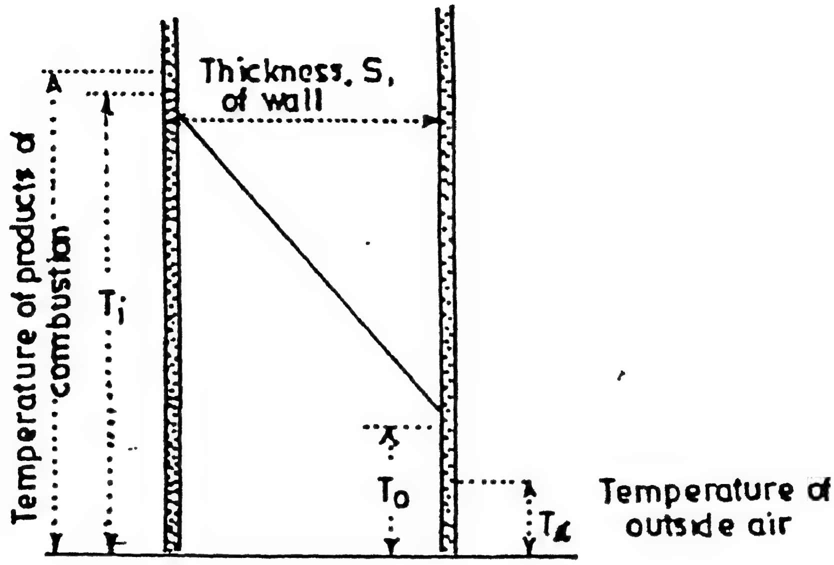

Fig. 19: Temperature gradient for steady flow of heat through a furnace wall, with equal pressure on both sides of the wall.

The heat losses discussed above are those incurred during steady, uninterrupted operation. In actual practice, operating periods ("on") alternate with idle periods ("off"). During the 'off' period, the heat gained in the refractories during the 'on' period is gradually dissipated, mainly by radiation and convection from the cold face. In addition, some heat is removed by air flowing through the furnace. Dissipation of stored heat is a loss, because the lost heat is again imparted to the refractories during the next on period.

It is extremely difficult to estimate the heat lost by circulation of air through burner openings and around poorly fitted doors. It is, however, possible to estimate the loss of stored heat that occurs by radiation and convection from the "cold face" while the hot furnace is idle.

For short periods of operation between long shutdowns, thin walls of insulating refractories are preferable, because little heat is stored in them. The heat lost by dissipation of heat stored in the refractories is determined by both the ratio of "on" (operating) time to "off" (idle) time, and the length of the cycle. If a furnace is operated 24 hr every third day, practically all of the heat stored in the refractories is lost. But if the furnace is operated 8 hr a day, not all of the heat stored in the refractories is dissipated.

(b) Heat Lost by Radiation through Openings

In Fig. 20, 1-1 is a hole in the furnace wall. An observer can see the interior of the furnace through 3, just as if that interior were a plane surface, or "diaphragm", located at 1-1. If the wall 1-2 were infinitely thin, the diaphragm could be seen from any point to the right of 1-1. The finite thickness of the wall, however, changes situation. It obstructs the direct radiation to an extent depending on the ratio of the wall thickness to the width opening.

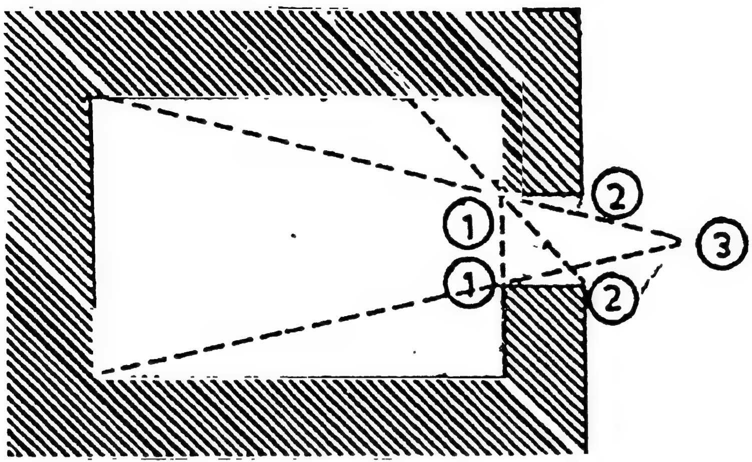

Fig.20: Diagrammatic illustration of heat radiation from opening

In (high temperature) furnaces with thick walls, semi-openings can be observed. Unless the binding is very strong, the bricks in the (furnace) interior expand considerably, while the outside layers expand very little. Through the gaps thus produced, the inner red-hot bricks are visible. An illusion is thus created that the observer can see the furnace interior through the gaps. The inner, red-hot bricks radiate considerable heat through the more or less wide cracks.

(c) Heat Lost by Furnace Gases Escaping Around Doors

The loss of heat that is caused by furnace gases passing through around doors, as indicated by arrows 5 in Fig. 18, is particularly hard to estimate. In electric furnaces, it is extremely small, unless the doors fit poorly. In combustion-type furnaces, some loss due to this cause invariably occurs, because such furnaces are operated with a slight pressure at the hearth level in the heating chamber. The reason for this method of operation is that a slight loss by gases passing outward is less detrimental than oxidation (and cooling) caused by infiltration of air into the furnace. With tightly fitting doors, the loss need not exceed 2 per cent of the total heat delivered to the furnace and averages one per cent. With loosely fitted doors, and with a flame or

jets of heated gases projected against the doors, it may easily reach eight per cent, and at times will even exceed that amount.

A distinction must be made between quantity of gases escaping around the doors and available heat carried out by these gases. If combustion has been completed in the furnace, practically no loss is incurred in batch-type furnaces by having gases escape around the doors. It makes no difference whether the gases escape around the doors or pass out through vents into the stack. If, on the other hand, combustion has not been completed, then a heat loss is incurred, because the gases complete their combustion out in the open instead of burning in the furnace. Conditions are different in continuous furnaces. If gases (even if completely burned) pass out through the discharge door, a heat loss is incurred, because these same gases would otherwise give up heat to the charge and would leave the furnace at a lower temperature.

(d) Special Losses

(i) Heat Loss Due to Part of the Stock Projecting out of the Furnace. With reference to Fig. 18, it may be noticed that there is heat loss due to dissipation of heat from metal projecting from the inside of the furnace into the open. Throughout the heating period, heat flows from the part that is inside the furnace to the part that is outside, and a portion of this heat is dissipated from the latter part by radiation and convection.

(ii) Losses to Trays, Conveyor Chains, and Rollers. Tray or other containers usually attain the same temperature as the stock, and the amount of heat that they take out of the furnace can be computed from their weight and from the heat-content. Chain conveyor parts, on the contrary, especially if thicker than the stock or less freely exposed to heat, do not attain such high temperatures as the stock. Judgment is required in estimating the amount of heat they carry out of a furnace. Hollow rollers of alloy steel with tapered ends, transmit little heat to the outside.

(e) Sensible Heat Carried Out of Furnace by Products of Combustion

In combustion-type furnaces, two additional sources of heat loss occur, namely those that are indicated by arrow 7 in Fig. 18. These losses are caused by the heat energy that the products of combustion take out of the furnace, either in potential form in the shape of unburned fuel or in kinetic form in the shape of sensible heat. To sensible heat may be added the latent heat of water vapour.

At low furnace temperatures, such as the one at 500°C, the stack loss (heat carried out by products of combustion) is affected little by the nature of the fuel. At higher temperatures, such as 1300°C, the difference in fuel economy is marked. The difference is caused by the variation in flame temperatures that can be attained by different fuels. A measure of this maximum temperature is the adiabatic (ideal or theoretical) flame temperature. It is defined as the temperature which is reached if the fuel is burned at a constant pressure with air at room temperature in a heat tight container. If a metal has to be heated to the adiabatic flame temperature, the fuel consumption would be infinitely high and the heating time would be infinitely long.

(f) Heat Loss due to Incomplete Combustion

Unburned fuel passes out of many industrial furnaces. In order to reduce oxidation of the charge, heaters sometimes keep the furnace atmosphere smokey. With the theoretically correct fuel-to-air ratio, combustion is not complete unless fuel and air are thoroughly mixed. Even with excess air, some combustibles are bound to be found in the waste gases. The amount of heat lost in this way, therefore, depends not only on the design of the burners and the furnace, but also on the operating requirements.

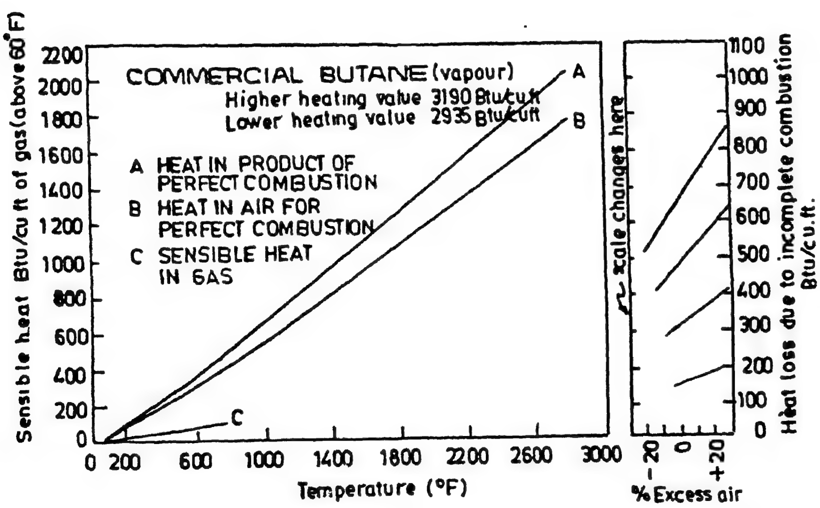

Fig.21: Heat in products of combustion of commercial butane

6.2.5.4 Heat Saving Methods and Apparatus for Industrial Furnaces

Heat may be saved by the use of one or more of the following methods.

(a) Reduction of wall losses, including storage loss.

(b) Application of high-temperature heat to a low-temperature charge without loss.

(c) Preheating of the stock by waste heat.

(d) Preheating of air or fuel (or both) by waste heat.

(e) Waste heat boiler.

(a) Reduction of Wall Losses

Furnace walls built of insulating refractories and encased in a steel shell reduce flow of heat to the surroundings. The loss is still further reduced by the insertion of ceramic fiber block between the insulating refractory and the steel casing.

The walls of tall furnaces are often built of dense firebricks. Heat loss that can be reduced by the application of insulation depends on the thickness of firebrick and of insulation, on type of insulation, and on continuity of furnace operation. The manner in which the saving in heat varies with three of these variables can be seen from Table 3 which refers to wall losses only and not to the total energy consumption of furnace.

Table 3

Reduction of Wall Losses by Insulation

(%)

Thickness of Firebrick Wall, in.	Continuous operation: 2½-in. insulation	Continuous operation: 5-in. insulation	1-week cycle 2½-in. insulation	1-day cycle 6 days per week 2½- in. insulation
4½	62	76	58	25
9	46	65	36	18
13½	38	57	20	14
18	35	53	15	12

(b) Heat Saving in Low-Temperature Furnaces and Ovens

The flame temperature of any fuel must be reduced before the products of combustion contact the charge. Fulfillment of this requirement presents no difficulty in high-temperature furnaces. But if the stock is to be

heated to temperatures between 425°C and 700°C, finding a good solution is more difficult. The temperature of products of combustion is often reduced by a mixture of excess air. This frequently used method is convenient but wasteful, because the waste gases carry not only the heat in the products of combustion but also the heat in the excess air.

The best method of saving heat in low-temperature furnaces is to increase the heat transfer by convection and mixing the hot products of combustion with cooler products that have already passed over the charge. Mixing may be accomplished by the jet action of the flame, as in Fig. 5 or by a hot fan as in Fig. 8. This is done to increase the convection component of heat transfer to the charge being heated. The rate of heat transfer by convection increases with greater density and greater velocity of the flowing medium. At a low temperature, density is greater than that at a high temperature. Therefore, cooler products that have already passed over the charge are mixed with the hot products of combustion.

(c) Utilization of Heat in Flue Gases

The values of sensible heat loss in flue gases (stack loss) for producer gas, natural gas and fuel oil energy source are provided in Fig. 22. The curves are based on fuel and air entering the burner at room temperature and also on 10 per cent excess air. At high temperatures, the loss becomes excessive. The desire to reduce the stack thermal energy loss had led to three heat salvaging methods:

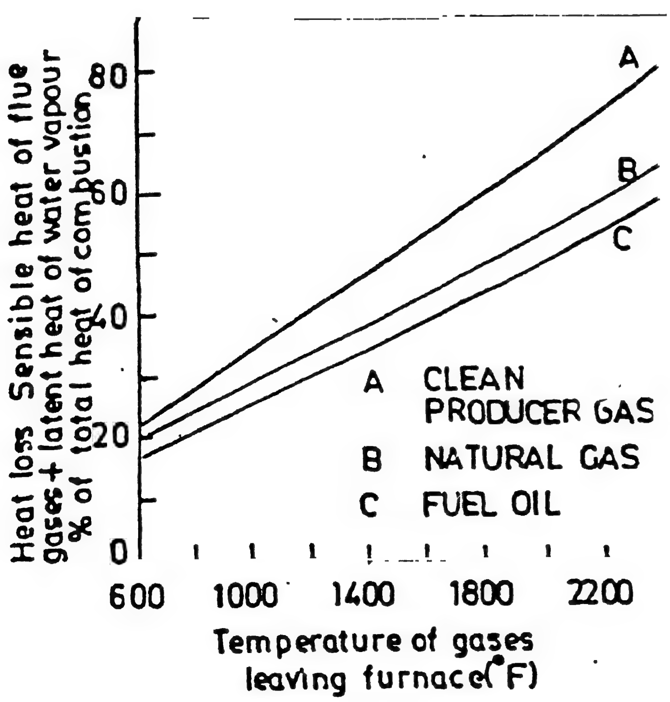

Fig.22: Stack loss as a function of flue temperature and form of fuel

(1) Preheating of cold stock by the flue gases.
(2) Preheating of combustion air (and of some fuels).
(3) Steam generation in waste heat boilers.

The method of preheating of cold stock was first used in preheating chambers, later in some continuous furnaces. If steel is preheated for forging or rolling, in a separate furnace by means of the waste gases of the high-heat furnace, it theoretically saves 30 per cent of the fuel.

(i) Preheating of Stock. Preheating furnaces (usually preheating pits) are in use for preheating ingots or large forging billets of tender steels. Such pieces are heated slowly to prevent cracking of the ingots. However, the pits are fired separately, and not by waste gases from the high-temperature furnace. A separate slow heating permits better control of temperature than heating by waste gases.

Preheating of stock by waste gases is widely practiced in the forging and hardening of tools. Its use is limited to the heating of pieces that can be lifted and handled by a man.

(ii) Fuel Saving by Preheating of Combustion Air. The second method of improving the economy of combustion-type furnaces consists of utilizing the heat of the stack gases for the preheating of combustion air, of fuel, or of both.

Before adopting this method, it is important to know (1) the fraction of the fuel that can be saved by the preheating of either the fuel or air to a given temperature, (2) The type and amount of heating surface required to get the desired preheat.

With burners of usual design, some excess air is needed to complete the process of combustion in the furnace, if the air is cold. If the air is hot, very little excess air is needed. Preheated air shortens the flame and causes the flame to become invisible if the air temperature is high enough. The quick combustion concentrates the heat near the burner and does not produce that long flame which extends all the way across the hearth. This may be corrected by working with a higher velocity in the burners. In either case the gases are clear, non-luminous unless the air temperature exceeds 600^{o}C. In this case, hydrocarbon fuels are partially cracked in the burner.

It should be noted that Fig. 23 and 24 refer only to furnaces having a constant temperature all over the hearth. They do not refer to those front-fired continuous furnaces that carry a dropping temperature

characteristics. Referring again to Fig. 23 and 24, it may be noted that considerable fuel savings can be effected by preheating the combustion air especially for furnaces in which high temperatures exist.

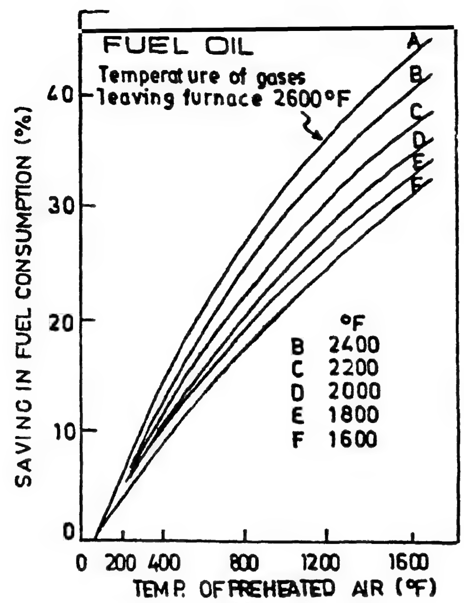

Fig.23: Saving of fuel oil (or coal) caused by preheating of air

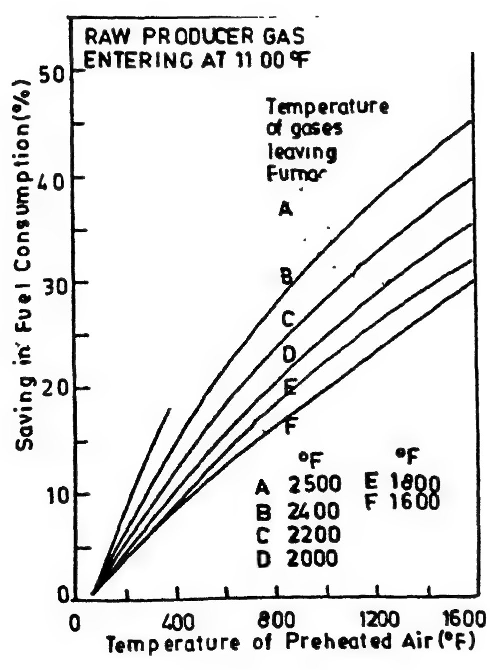

Fig.24: Saving of producer gas caused by preheating of air.

(iii) Recuperators. The two existing types of preheating devices are the recuperators and the regenerators. Recuperators may be subdivided into three classes, according to the flow of stack gases and of air, although combinations of the classes are often found. The three types, counterflow, parallel-flow, and cross-flow, are diagrammatically shown in Fig. 25, 26, and 27. For the first two types, the distribution of temperature along the path of the gas and air flow can be represented graphically in a rather simple manner (see Fig. 28), but for the cross-flow, the diagram is more complex. It is, in a measure, represented by Fig. 29. Only average temperatures (referring to up-and-down location) are shown, because the temperatures in and around the tubes vary from top to bottom.

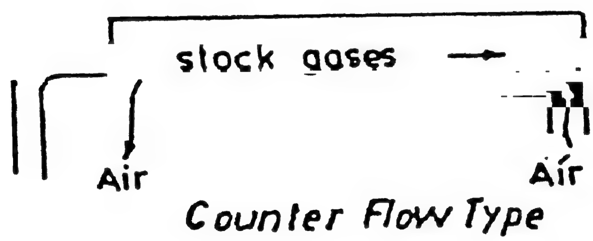

Fig.25: Counter flow recuperator

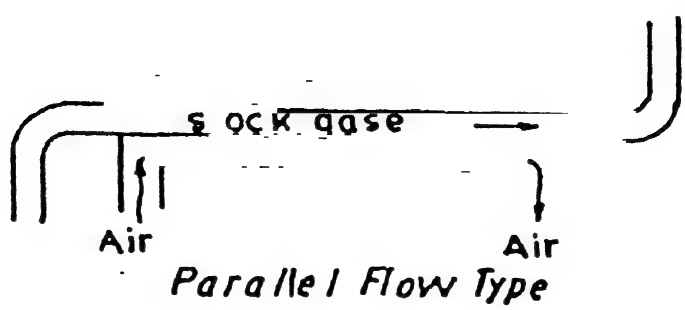

Fig.26: Parallel-flow recuperator

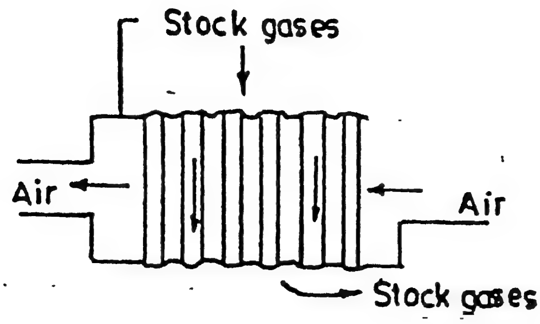

Fig.27: Cross-flow recuperator

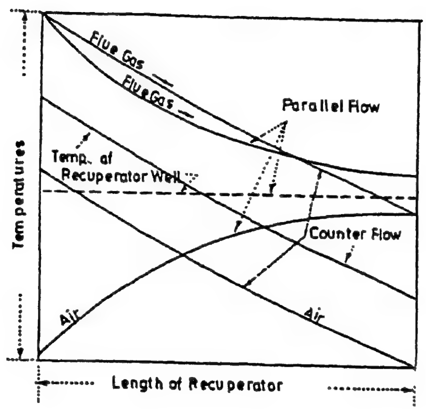

Fig.28: Temperature distribution in recuperators

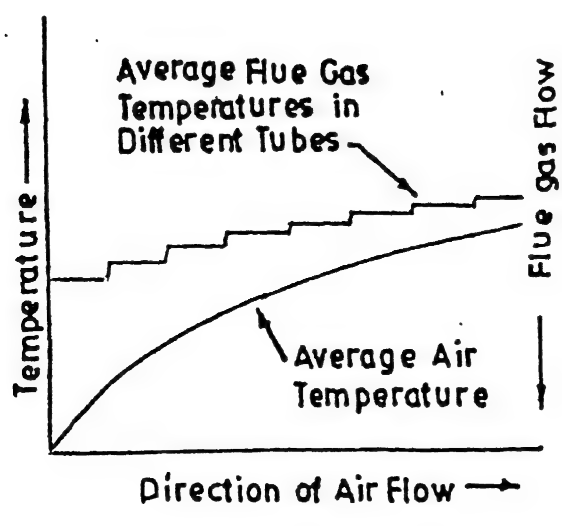

Fig.29: Temperature distribution in a cross-flow recuperator

It may be readily observed from the illustrations that the counter flow type allows the highest temperature of preheat to be reached, whereas the parallel-flow type gives the lowest maximum temperature of the recuperator walls. For that reason it is sometimes used in connection with metallic recuperator walls, the temperature of which must be kept comparatively low. In some designs a combination of these types is adopted. The cold air is first caused to circulate around the hot end of the tubes or plates to keep them cool, and then is bypassed to the cold end, where it flows with a combination of crossflow and counterflow toward the hot end again.

(iv) Regenerators. Many different settings of bricks have been devised for the purpose of increasing heat transfer in regenerators. For the same purpose and also for increasing stability, new shapes of bricks for regenerators have been designed. Among the many inventions, only those are of value that increase the area of flow from the bottom of the regenerator to its top, while keeping the heat-exchanging surface constant.

Continuous Regeneration. Alternating of flame direction in furnaces is often inconvenient and is sometimes impossible, as, for instance, in blast furnaces. For both reasons several designs have appeared for making the furnace recuperative (with constant direction of flame) while making the heat-salvaging equipment regenerative. These designs consist either of a plurality of cyclical operated regenerators or else of a regenerator with movable parts. Blast-furnace stoves are a typical example of the first kind.

(v) Waste-Heat Boilers. The third method of utilizing the heat of the products of combustion is the generation of steam. The amount of steam that can be generated in unit time from a given furnace depends on the flue gas flow rate, its temperature at entrance to the boiler, and the temperature to which it can be cooled. The temperature of the flue gas at entrance to the boiler should be approximately equal to the furnace temperature, except when the boiler is used in connection with a continuous furnace, in which case the flue-gas temperature depends on the rate of heating. In heating furnace practice, waste heat boilers are practically never used if the furnace is equipped with either a regenerator or recuperator.

Fig. 30 shows the number of boiler horsepower (at 8,000 kcal/hr) that can be extracted from the products of combustion of a furnace rated at 2,40,000 kcal/hr with varying furnace temperatures and with three stack temperatures. The second type of graph (Fig. 31) gives the heating surface that is necessary per boiler horsepower with different furnace temperatures and three stack temperatures. Much waste heat is available from 1200°C furnaces and a comparatively small amount is available from 750 to 900°C furnace, unless fan draft is used and the gases are cooled down to a low temperature.

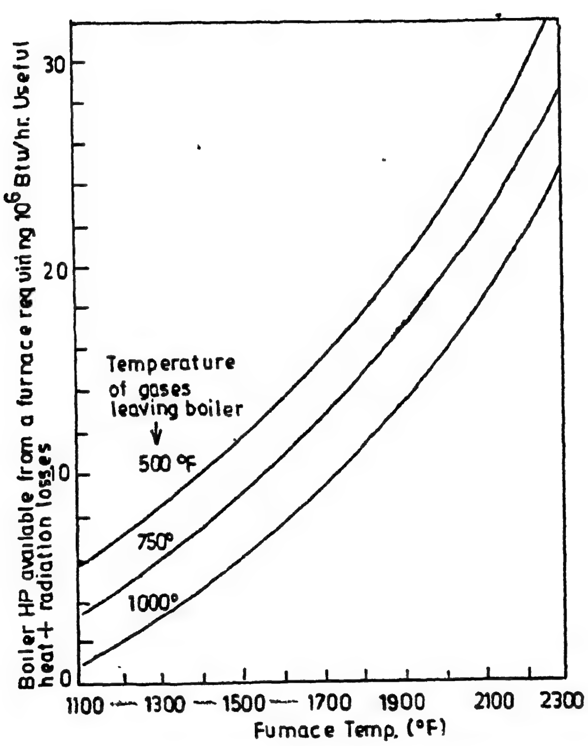

Fig.30: Boiler horsepower available from unit-size furnace under direct-fired conditions. One boiler horsepower equals 33..475 Btu per hour.

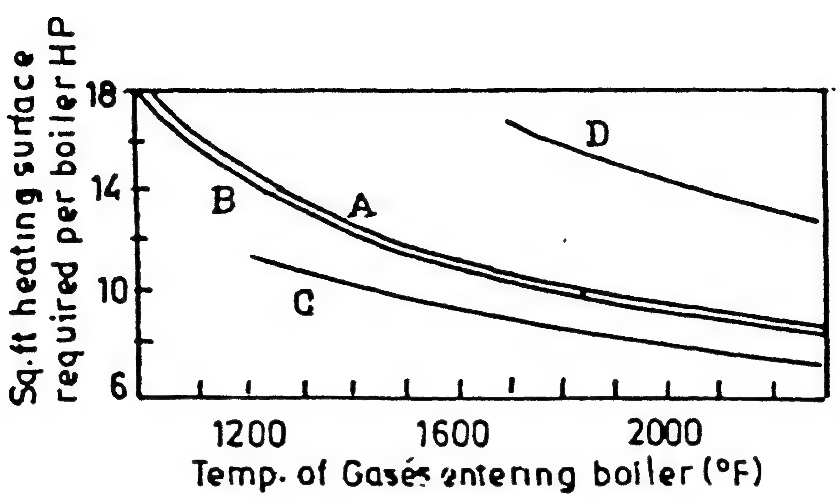

Fig.31: Heating surface required for waste-heat boilers, with clean surfaces. Curve A is for draft loss through boiler of 2-in. water; coefficient of heat transfer, K = 6.0; curves B, C, and D are for draft loss = 0.5; K = 4.0.

A and D 500°F temperature of gases leaving boiler
B 750°F temperature of gases leaving boiler
C 1000°F temperature of gases leaving boiler

In countries with high fuel cost and low labour cost, even the heat in water that flows through skid pipes is utilized in waste heat boilers. In order to prevent deposits of scale in the skid pipes, the circulating water must either be treated or else be condensate. The water is under pressure and may be heated to a high temperature; heating, of course, depends upon the steam pressure in the boiler. With modern boiler pressures, the water may be heated to approximately 250°C. The high water temperature reduces heat loss in the furnace. Steam bubbles accidentally formed in the skid pipes are very small at high pressures and are harmless. This method of heat salvage requires a close coordination between furnace operation and power-plant operation.

PROJECTS

1. (i) Quantify losses in a furnace in your plant/workshop, and determine the overall efficiency

   (ii) Identify various energy saving measures for the furnace

   (iii) Determine the investment required and the pay-back period

2. Repeat (i), (ii) and (iii) for other furnaces in your plant/workshop

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Section 3: Fluidized-Bed Furnaces

6.3.1 Introduction

The conventional way of heating metals for heat treatment is to use furnaces fired with coal, oil or gas, or heated by electricity. While the use of these furnaces in specific cases cannot be avoided, many types of heat treatment furnaces can be replaced with fluidized-bed furnaces (FBF), which are inherently more energy efficient. In this section, a brief discussion of the application of FBFs in heat treatment facilities is presented.

6.3.2 Fluidization and Fluidized-Bed Furnaces

Fluidization is a physical phenomenon in which a gas flows through a bed of particles with a velocity large enough to ensure that the pressure drop across the bed is equal to the weight of the bed per unit bed cross-sectional area. The particles in such a condition are in a state of dynamic equilibrium and exhibit an overall circulation pattern. The term fluidization is applied because of the similarity of such a system with a fluid in a container which finds its own level, exhibits buoyancy, and has a dynamic behaviour described by the Navier-Stokes equation. These characteristics of a fluidized bed (especially that of a gross solids circulation pattern) make it very attractive for use as a high temperature furnace.

The high temperature in such a FBF is achieved either by electric heating, or by mixing a combustible gas (natural gas, propane, coal gas, etc.) with the fluidizing air, and igniting the air-gas mixture in the bed. The schematic flow diagram of such a system is shown in Figure 1. The heat causes the gases and the fluidized solids to achieve high temperatures. The continuous solids movement leads to the hot particles impinging on the immersed surface (which is to be heated), transferring heat to it (and being cooled down in the process), and then moving back to the bulk of the bed where they are heated up again. Thus, the primary mode of heat transfer is unsteady - state conduction from the hot, high heat capacity particles as opposed to steady - state gas convection from the combustion gases in conventional furnaces. In both cases though, the heat transfer is significantly enhanced by radiation due to the high furnace temperature.

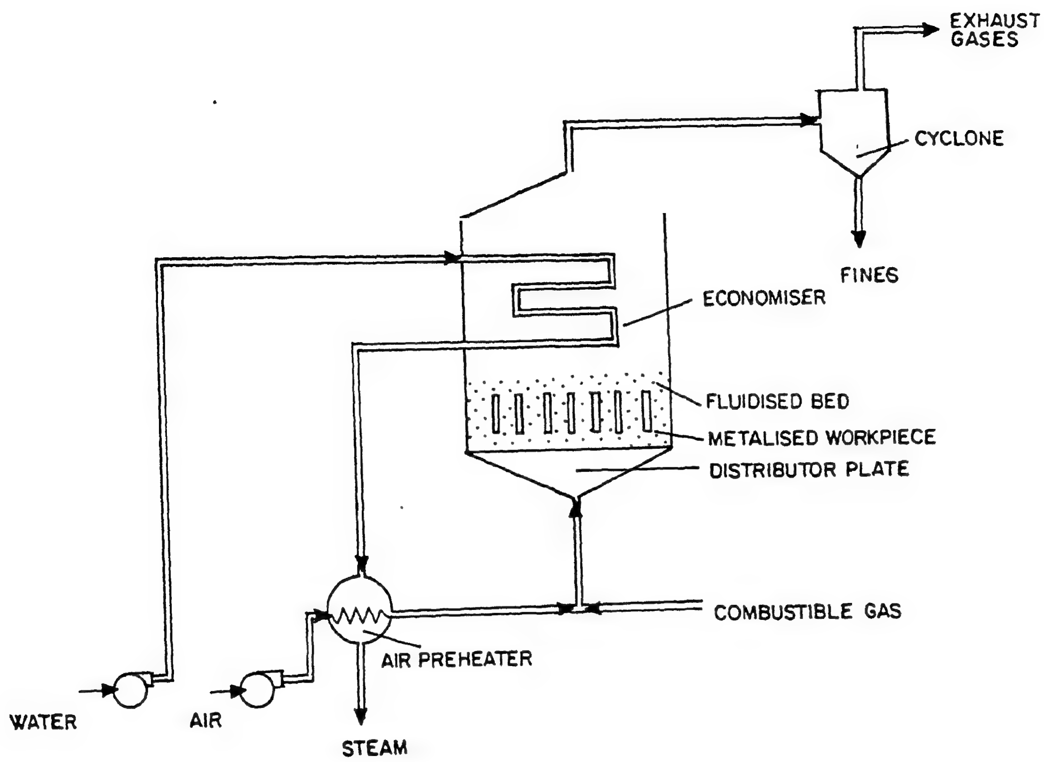

Fig.1: Schematic representation of a fluidized-bed furnace

Mathur (1) has found that a stoichiometric air-gas mixture can produce a bed temperature, T_b, as high as 1175° K. Reducing the gas flow rate decreased the bed temperature, and the bed temperature could be rather precisely controlled in the range 700° - 1175° K by suitably varying the gas flow rate. The lower temperature of 700° K was achieved when the gas flow rate was half the stoichiometric amount. Reducing the gas flow rate further was found to result in flame instability. Temperatures less than 700°K are typically achieved by electric heating. The electric heaters are placed around the fluidized bed, and the heat is carried away from the walls by the fluidized solids. FBFs typically exhibit temperature uniformity of +/-3° K throughout the bed with greater uniformity in the work area.

6.3.2.1 Fluidized-Bed Furnaces

The application of fluidized beds as heat treating furnaces is rather recent, for the past 15 years or so with much of the early work being done in Russia and East Europe. The boom came alongwith the oil and energy crisis and the suddenly felt importance of quality at a low operating cost.

Within a very short time, FBFs became extremely popular first for tool steels and soon for all other neutral and surface treatment processes. Present estimates stand at around 8000 furnaces worldwide, which is rapidly growing.

6.3.2.2 Types of Fluidized-Bed Heat Treating Furnaces

The last few years have seen the development of various types of heat treating furnaces based on the fluidized-bed phenomena. The most popular ones, as evidenced by the number of such furnaces installed, is the externally heated variety. Here, the heat is input from outside the container (retort) with either gas or electricity. Other noteworthy types that were thrown up in the search for the ideal furnace were as follows:

The Internal Combustion Variety. Where the fluidizing gas was combusted within the bed and also used as a heat source. Understandably, the heat up rate was quicker but problems were caused by the differing degree of gas required for fluidizing and for combustion as well as by the difficulty of measuring and maintaining atmospheric composition. To solve these the bed design became complex and in due course, unpopular.

The Submerged Combustion Variety. Like in heated swimming pools, special burners were used at the surface of the bed and the heat transmitted downward. Though not very popular now, this design has the promise and potential especially for reheating applications in the forging industry.

6.5.3 Advantages of FBFs over Conventional Furnaces

Four primary, inherent properties of the fluidized bed make them a superior alternative to every other type of heat treating furnace for most applications. These are:

i. The high degree of Heat Transfer

ii. The high degree of Temperature Uniformity

iii. Its Flexibility: the ability to operate at any temperature (up to design limits) and with any mixture of fluidizing gases (heat treating atmospheres)

iv. Its physical state; in terms of being dry, clean, non-toxic, etc.

These properties yield the following specific advantages:

(i) **Low Operating cost.** The high heat transfer rate (4 to 25 times faster than convection/radiation furnaces) cuts down cycle times. Larger tonnages can be processed in smaller furnaces. When not in use, the furnace can be switched off and need not be idled. When off, even over-night, the bed retains most of its heat and only needs incremental heating the next day.

The need for effluent treatment and disposal does not arise and pre-/post-cleaning expenses reduce. All these and other features like low maintenance, no fuel handling, lower LPG storage, no gas generator, etc., combine to yield an operating cost per kilogram at 50-70 per cent of that of conventional heat treating equipment.

(ii) **Throughput quality.** The high degree of temperature uniformity (+/-3^{o}C, typical) causes extremely uniform heating of all components, even in very dense loads. Distortion is reduced by the bed buoyancy and uniform heat up from surface to core.

During case treatments, non-uniform case depth does not occur. The component surfaces are continually exposed to fresh reactive gas under pressure and are gently scrubbed by the particles which also remove carbon build-up on edges and corners. Dense loads can be processed without much care in component positioning and spacing.

(iii) **Low maintenance.** There are no moving parts like fans, conveyers, etc. as in atmospheric furnaces and hence, no attendant maintenance problems. Separate gas generators are not required. Periodic furnace burnouts are not needed. Soot formation does not pose problems as the soot deposits on the particles and is burned/blown off at the bed surface. The alumina particles are inert and do not require rectification, regeneration or monitoring. The heating uniformity and the heat retention ensure longer life for furnace alloys.

(iv) **Low capital cost.** FBFs cost less than equal capacity, vacuum-sealed quench- and pit-type furnaces and even salt baths (when effluent treating and safety equipment costs are added). As one furnace performs many processes, additional furnaces for specific low volume applications are not required.

(v) **Pollution free.** As FBFs are free from poisonous gases, they do not attract the provision of health and pollution laws. It is extremely safe for those operating them. Effluent treatment and disposal equipment are not required.

(vi) **Low pre-/post-cleaning.** Pre-cleaning and drying of components required for processing in atmospheric and salt bath furnaces are not required when using FBFs. Oil and moisture on the components and jig simply vaporize without the hazard of explosion. Post-treatment cleaning is also greatly reduced. Some alumina adhering to threads blind holes, but these are easily washed or blown off.

(vii) **Ease of operation/training.** The operation of an FBF is extremely simple and safe. It involves only setting the desired temperature and gas flow (done automatically in certain models) and immersing the components. At the end of the cycle, the components are lifted out and the furnace is switched off while waiting for the next batch. The lack of any type of hazard makes operator training very simple.

(viii) **Flexibility of operation**

Temperature: An FBF can be operated at any temperature from sub-zero right up to its rated limit. Most furnaces for surface treatments are rated up to 1050^oC and 1150^oC.

Atmosphere: Any gas mixture can be used for fluidization. Also a fresh gas stream replaces the existing gas stream within minutes of the fresh gas entry. Consequently, it is possible to change the atmosphere inside an FBF within seconds without the need for conditioning.

These two features give the FBF a versatility that is unmatched by any other furnace. It is possible to harden and carbonitride in the morning, carburize in the afternoon, temper and nitrocarburize in the evening and nitride overnight.

A single furnace can perform carburizing, carbonitriding, nitriding, nitrocarburizing, oxynitriding, soft nitriding, neutral hardening, tempering, steam blueing, black oxiding, normalizing, annealing, preheating, aging, homogenizing, stress relieving, thermal shock testing, plastic stripping, quenching, etc. When a second furnace is added, it is also possible to marquench, austemper, isothermally anneal, etc.

FBFs have heat transfer rates that are ten times those in conventional furnaces under otherwise identical conditions. This implies that an immersed surface can be heated to a desired temperature in an FBF in one-tenth of the time required in a conventional furnace. The energy requirement for any heating process in an FBF is therefore, only one-tenth of that required in a conventional furnace. FBFs consequently have the potential for 90 per cent energy savings over a conventional furnace.

In the alloy steel industry, commonly used heat treatment methods are annealing, normalizing, hardening, tempering, and carburizing. All these methods involve the heating of steel (to different temperatures in different methods), maintaining it at a particular temperature for some time (also referred to soak time), and then cooling it back to room temperature. The soak time and the rate of cooling are the primary characteristics of a heat treatment method, which determine the final steel microstructure.

The heating and soaking are carried out in a hot furnace, while the cooling may be carried out in the furnace itself (after the furnace heat is switched off, and the furnace and metal then cool at the same rate), in air, or in water or oil. Furnace heating is, therefore, required during heating and soaking, and potential energy savings due to the use of FBFs instead of conventional furnaces will occur during these processes.

It is, of course, not being argued here that FBFs can replace all conventional furnaces in the alloy steel heat treatment industry. Carburizing and controlled atmosphere heat treating, for example, cannot be carried out in the direct-fired FBFs described here. This is because air is essential in the direct-fired FBFs to maintain gas combustion. Air would cause the carbonaceous material in carburizing to burn itself, and would completely defeat the purpose of inert environment in controlled atmosphere heat treating. These special operations are possible in externally fired FBFs in which a special controlled environment chamber is located within the FBF. In such externally fired FBFs, however, the effective operating temperatures would be lower than in direct-fired FBFs because of the temperature losses due to the chamber walls. It is estimated that 50% of all alloy steel heat treatment processes are amenable to operation in direct-fired FBFs.

During most heat treatment processes (in conventional furnaces), the heating time is 20-24 hours, and soak time is 7-9 hours (6). The soak time is calculated on the basis of time required for phase transformation to occur, and would therefore be the same in both FBFs and conventional furnaces. The heating time in a FBF would however reduce to one-tenth that in a conventional furnace, and, therefore, whereas a conventional furnace would have an on-cycle period of about 30 hours, the on-cycle period in a FBF would be only 10 hours. This implies that the heating load reduces to one-third that in a conventional furnace. It is estimated (7) that in conventional furnaces, the heat load is 1470 MJ/tonne of finished alloy steel, and the total energy requirement (including heat load) is 2030 MJ/tonne. A two-thirds reduction in the heating requirement implies that the total energy requirement in a FBF is only 1050 MJ/tonne, thus providing a saving of 980 MJ/tonne or 48 per cent of the energy requirement in a conventional furnace.

6.3.4 Cost of Fluidized Bed Heat Treating

In this section, the cost of FBFs are compared with salt bath, atmosphere (pit and sealed quench) and vacuum furnace processing.

The results of a study, conducted in UK in 1979 and adjusted to Indian costs of gas, electricity and labour are given in Fig. 2a & 2b.

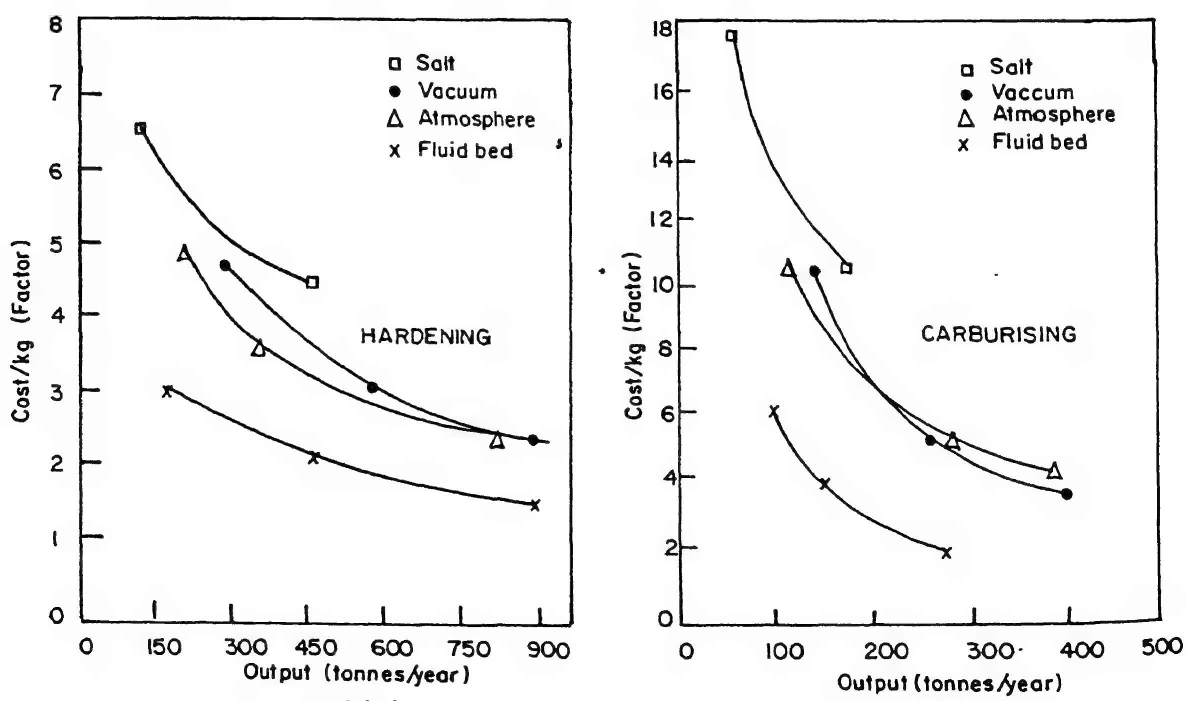

Fig.2(a) Fig.2(b)

Cost comparison of fluidized bed furnaces vs conventional equipment

The costing included energy, all process consumables, labour, jig and maintenance costs as well as depreciation and cost of capital.

As can be seen in Fig. 2a & 2b, fluidized beds were found to yield the lowest operating cost per kilo processed. The next least costing processes are vacuum, and atmosphere with salt baths being the most expensive. This is true for both the carburizing as well as the hardening process. This low operating cost is due to various features of the fluidized-bed furnace, described earlier and summarized below.

1. High heat transfer - shorter cycle times

2. Ability to switch off - no 'idling' energy consumption

3. High heat retention - retains heat when switched off. Needs only incremental heating even after a long 'off' period

4. The same furnace can be used for a variety of treatments

5. The temperature uniformity allows precise control: therefore, over-soaking is avoided

6. Downtime is minimum

7. No need for effluent treatment and disposal

8. No precleaning and minimum post cleaning

9. No need for gas generator and associated maintenance

10. No fume handling, duct work, LPG bulk storage, etc.

11. Low furnace maintenance - no moving parts

12. No furnace "burn outs"

13. No explosion hazard and related safety equipment

14. No extensive gas analysis and control requirements

15. No process consumable like salt

16. Low process gas consumption. And many other features.

6.3.5 Manufacturer in India

The only Indian manufacturer of FBFs is M/s Fluidtherm Technology (P) Ltd.*

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* (No. 132, 3rd Main Road, Ambattur Industrial Estate, Madras - 600 058) who fabricate FBFs for a wide variety of applications.

PROJECT

Conduct a techno-economic feasibility study of replacing some of the furnaces or addition of furnace(s) at your plant/workshop with fluidized-bed furnaces.

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Section 4: Energy-Efficient Burners

6.4.1 Introduction

In the combustion process, the most important feature is the production and control of a flame. Flames are associated with combustion of a flowing stream of fuel, whether it is solid, liquid, or gas. In general, combustion denotes any fast exothermic gas phase chemical reaction and a flame is defined as combustion which propagates subsonically through space, usually accompanied by visible radiation.

The heat from the combustion process stems from the release of energy when the carbon and hydrogen atoms in a carbonaceous fuel react with oxygen. Heat is evolved irrespective of whether a solid, liquid or gaseous fuel is used in application. The physical form of the fuel, however, will affect the method by which fuel and oxidant are mixed and ignited. For combustion to occur,it is necessary to bring in the following conditions:

1. Fuel and air preparation

2. Proportioning of fuel and air

3. Mixing of fuel and air

4. Raising the temperature of the mixture for proper combustion

5. Ensuring complete combustion

6. Transferring the heat from the combustion products effectively.

Generally, the job of the oil burner or the mechanical stoker is to condition the fuel and send the fuel and air mixture to the combustion chamber. In one type of gas burners, the gas and air flow separately into the combustion chamber and intermix with each other as the burning proceeds. The flame thus produced is referred to as "diffusion flame". In another type, the gas and air are intimately mixed while cold, and burned as they leave the mixing chamber.

6.4.2 Technical Background

A large portion of energy used in industry is produced by combustion of fossil fuels, viz., coal, oil and natural gas. Boilers, furnaces, air heaters, and kilns are some of the equipment which rely on combustion process (burning of fuel). The device which accomplishes the

combustion process is known as burner or a fuel firing system. The primary functions of a burner or a fuel firing system are:

- to volatilize solid and liquid fuels
- to mix fuel and air
- to initiate and maintain ignition
- to supply fuel and air at proper flow rates and pressures so as to facilitate the above mentioned functions efficiently and safely at any required rate of heating.
- to position flames at areas of useful heat release

There are specific types of burners available for burning solid (coal), liquid (oil) and gaseous fuels to optimize their use for a wide range of process heat generation equipment. Satisfactory operation of any combustion system depends to a large extent on selection of the correct type of burner for a given application. A proper selection has to be made to suit the divergent requirements of industrial furnaces such as range of operation, type of fuel, shape of combustion chamber and desirable pattern of heating, temperature and furnace atmosphere.

In the last few years, there had been several advances in burner technology from energy efficiency point of view. As a result, a few energy-efficient burners, viz., low-excess air film burners, self-recuperative burners, regenerative ceramic burners, high velocity burners and submerged burners, have been developed abroad. Their use in various industries in U.S.A. and U.K. has demonstrated that a significant amount of fuel (oil and gas) can be saved if industries make use of these burners. A brief description on each of the energy-efficient burners is given below.

Low-Excess Air Burner. These burners are claimed to achieve combustion of oil and gaseous fuels with as little as 5-10 per cent excess air against 25-40 per cent in normal low-pressure burner. In low-excess air film burner, the stream of liquid fuel has a shape of a thin cylinder. Air is passed through this cylindrical stream which leads to the formation of a very thin film in the form of a hollow cylinder. Part of the primary air, which is at about 700 mm water gauge (w.g.), is supplied along the areas of cylindrical film and the rest along the periphery. Impingement of air on both sides of the hollow cylindrical film divides the film into very fine droplets resulting in a very efficient combustion. Operation at low excess air brings about the following advantages:

- reduced stack losses resulting in fuel saving

- increase in radiation and convective heat transfer due to higher flame temperature resulting in lower heating time and increased capacity utilization of the furnace

- less chances of formation of SO_2 under low excess air operation resulting in less corrosion.

It has been observed that fuel savings of the order of 10-15 per cent can be achieved through use of these burners. They have been successfully installed for various heating applications in forging plants, rolling mills, mini steel plants and heat treatment units. Decrease in NO_x and particulate emissions owing to these burners have been reported in the literature.

Self-Recuperative Burner. The traditional way of recovering heat, in a simple furnace, has been to use centralized recuperators, allowing outgoing exhaust gases to heat the incoming combustion air on its way to burners. In self-recuperative burners, hot combustion gases in the furnace are drawn back into the burner assembly. The flue carrying these gases is situated next to those carrying incoming cold air to the burners. Heat is transferred to the cold air over the common surface with the result that air reaching the burners is preheated. Higher preheat temperature results in less fuel requirement to maintain the required temperature within the furnace. A schematic of self-recuperative burner is shown in Fig. 1. It consists of a high velocity nozzle-mixing burner surrounded by a counterflow gas-to-air heat exchanger. The outlet for the flue gases is located on the top of the burner enclosure. All recuperative components are made of heat resisting steel.

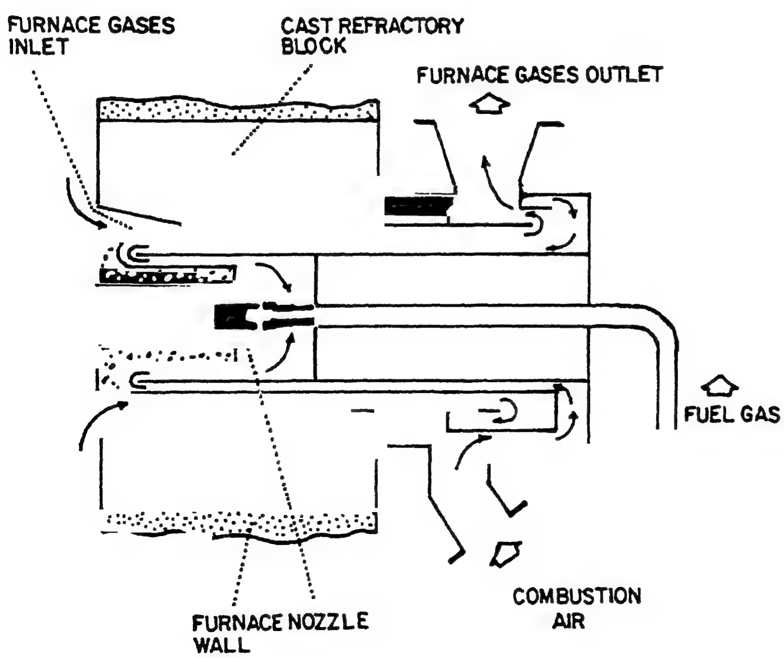

Fig.1: Schematic diagram of a self-recuperative burner

There are a number of applications where this burner has demonstrated its better efficiency and fuel economy. These include forging furnaces, reheating furnaces, intermittent kilns and heat treatment furnaces. Fuel savings of up to 35 per cent can be achieved through use of these burners. Further, savings of up to 50 per cent are possible with adequate furnace pressure control and a closer control of the air/gas ratio. In small- and medium-sized furnaces where the use of recuperator down-stream of the main heating line is not found economically viable, the recuperative burner, with its own self-contained recuperator, offers the users of small- and medium-sized furnaces an opportunity to save considerable quantities of fuel. The potential fuel saving in an existing furnace depends on how much heat is being wasted, i.e., on the temperature of flue gases; the actual saving depends on how much is recovered, i.e. on the increase in temperature of combustion air.

Regenerative Ceramic Burner: In conventional recuperators the amount of heat removed from the exhaust gases is limited by the physical size of recuperators. Their use is also limited to lower furnace exhaust temperatures due to the constraint on materials of construction. Because of much larger surface area in a regenerator compared to a recuperator of the same volume, heat recovery potential through a regenerator is much greater than that of a recuperator. This fact has led to the development of a regenerative burner. A regenerative ceramic burner unit comprises of at least two burners, two regenerators, a flow reversal system and associated controls. The burners and regenerators can be closely coupled or joined by a refractory lined duct to suit the space available on site. While one burner fires using air fed to the base of its regenerator, the other burner acts as an exhaust port drawing off flue gases thereby heating its surface (packed bed of ceramic material). When this regenerator is sufficiently heated, the system is reversed by means of valves (see Fig. 2). The regenerator which was previously cooled is now reheated in turn by flue gases which leave the furnace via its associated burner.

Regenerative ceramic burners can be used to meet a broad range of industrial applications including ladle heating, heat treatment, metal and glass melting, and in ceramic kilns. The operating temperatures may be as high as 1400^{o}C. The major advantage is the potential to save up to 65 per cent fuel compared to cold air burners and up to 30 per cent over conventional recuperators. In addition, improved temperature distribution, which results in enhanced product quality, and hence, lesser rejects is another advantage. Since early 1983, regenerative ceramic burners have been applied successfully to glass melting, forging, annealing, aluminium remelt and heat treatment of steel strips, tubes, plates and castings in U.K., Europe, U.S.A., Japan and Australia.

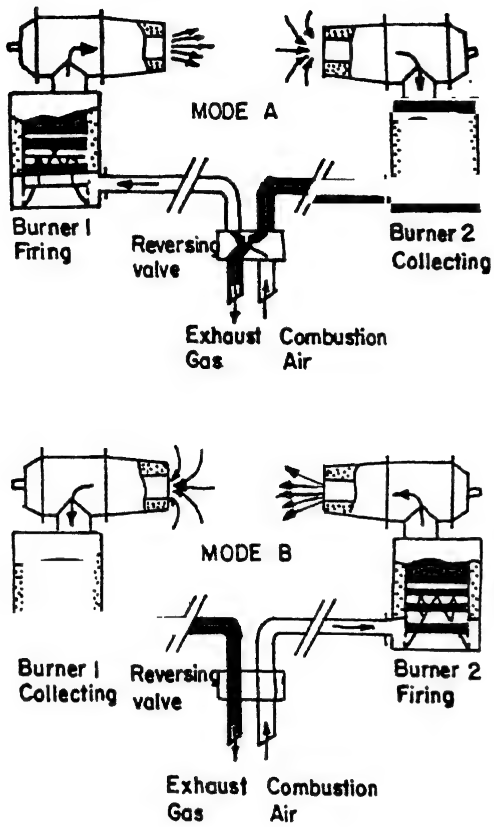

Fig. 2: Schematic diagram of a regenerator burner

High Velocity Burners. A high velocity burner employs the concept of very rapid circulation of combustion gases within the furnace chamber. It is suitable for applications where a high heating rate and temperature uniformity is required. It produces high rates of stirring, mixing and recirculation of the furnace atmospheres resulting in increased convective heat transfer to the load. Through the use of high velocity burners, it is possible to fire a furnace at very low temperature, promoting a high rate of heat transfer even with small temperature differentials between the furnace and the load. The positively induced heat transfer produces uniform load temperatures while following a planned temperature cycle. Further, rapid heat transfer saves considerable time and fuel in many applications such as stress relieving of steel fabrications, and reheating of billets for hot working in both ferrous and non-ferrous industries. High velocity burners are designed for use with light and heavy oil or gaseous fuels. Generally, high velocity burners can be designed to receive preheated combustion air at temperatures up to 600°C. To achieve higher fuel savings, the burner is used with conventional recuperator.

Submerged Combustion Burner. Submerged combustion burners are not new but their application in heating of process liquids needs to be mentioned due to their higher efficiency and offering opportunities for energy conservation. A schematic diagram of a submerged combustion burner manufactured by Hygrotherm Engineering Ltd., U.K. is shown in Fig. 3. The burner fires through a tube similar to a radiant burner tube, which is immersed in the liquid to be heated. Gaseous products of combustion are discharged into the liquid at the base of the tube. Hot gases break into small bubbles and rise to the surface between the combustion tube and a draught tube. This promotes turbulence in the space between the two tubes. Heat transfer from bubbles to the liquid is fast because of increased surface area created by the large number of bubbles formed. Since the combustion takes place where it is required to use the heat, no additional heat exchanger is required resulting in a better overall efficiency, and hence fuel savings.

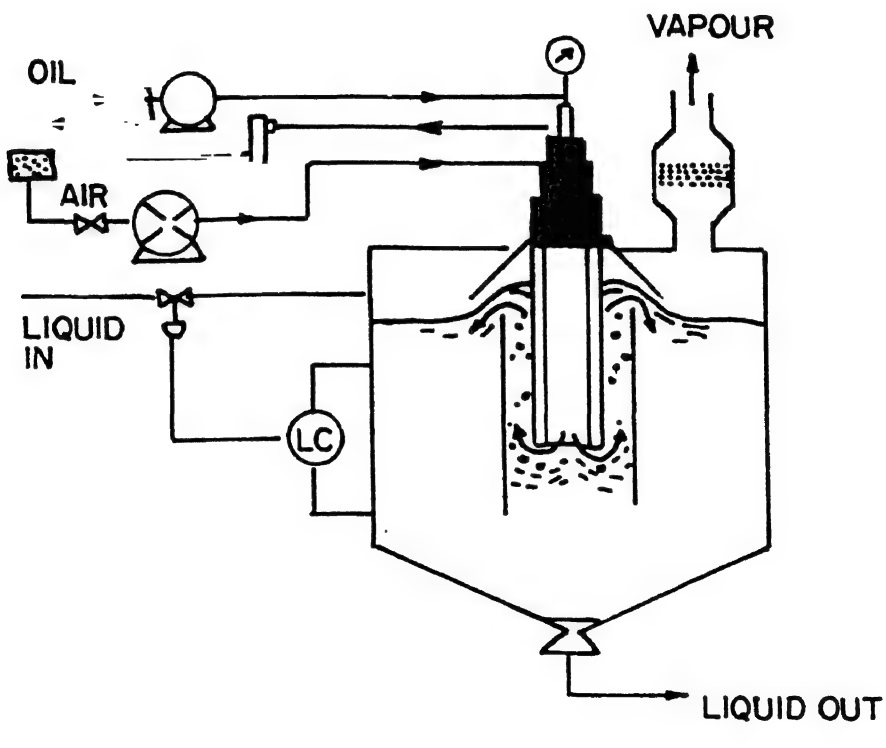

Fig.3: Schematic diagram of a submerged combustion burner

6.4.3 Tips for Efficient Operation of Burners

1) Start up

a) Before start-up drain off cold oil

b) Check for correct sized burner/nozzle.

c) Establish air supply first (Start blower). Ensure no vapour/gases are present before light up.

d) Ensure a flame from a torch or some other source placed in front of the nozzle.

e) Turn on the (preheated) oil supply

2) Operations

a) Check for correct temperature of oil at the burner tip (consult viscosity vs. temperature chart).

b) Check for the correct air pressure for the LAP burners (25" to 30" w.g. or 63.5 cm to 76.2 cm air pressure is commonly adopted).

c) Check if oil is dripping near the burner.

d) Check for flame fading/flame pulsations.

e) Check for positioning of burner (ensure no flame impingement on refractory walls or charge).

f) Adjust the flame length to suit the conditions (ensure the flame does not leap out of the furnace).

3) Load Changes

a) Operate both air and oil valves simultaneously (if it is a self-proportioning burner, operate the self-proportioning lever. Do not adjust valve only in oil line).

b) Shut the blower after a lapse of few seconds (ensure gases are purged out of the combustion chamber).

c) Do not expose the burner nozzle to the radiant heat of the furance. (When oil is shut off, remove burner/ nozzle or interpose a thin refractory between nozzle and furnance.

4) Maintenance

Burners should be dismantled and cleaned periodically, preferably as recommended by manufacturer (always keep spare burners ready).

Section 5: Waste Heat Recovery And Utilization

6.5.1 Introduction

Waste heat is defined as heat which is rejected from a process at a temperature sufficiently above the ambient temperature to permit extraction of additional heat from it. Sources of heat can be divided according to temperature ranges:

(a) High temperature range, i.e., temperature above 650°C

(b) Medium temperature range, i.e., temperature between 650°C & 230°C

(c) Low temperature range, i.e., temperature below 230°C

High and medium temperature waste heat can be used to produce process steam but one would explore the possibility of using the high temperature energy to do useful work before the waste heat is extracted.

In the low temperature range, waste energy can be utilized for preheating purposes.

6.5.2 Sources of Waste Heat

Waste heat sources are generally available in the form of exhaust gases coming out from the exhaust of different industrial process equipment. Given below are the temperature of waste gases from Industrial process equipment in the high and medium temperature range (Table 1). Table 2 lists some heat sources in the low temperature range.

Table 1

High- and Medium-Temperature Heat Source

Type of Device	Temperature (°C)
1. Metal refining furnace	650-1650
2. Steel heating furnace	930-1040
3. Copper reverberatory furnace	900-1090
4. Open hearth furnace	650-710
5. Cement kiln	620-730
6. Glass melting furnace	980-1540
7. Hydrogen plants	650-980
8. Steam boiler exhaust	230-480
9. Gas turbine exhaust	370-540
10. Reciprocating engine exhaust	310-590
11. Heat treating furnace	430-650

Table 2

Low-Temperature Heat Source

Source	Temperature (^{o}C)
(a) Process steam condensate	50-90
(b) Cooling water from	
i. Annealing furnace	65-230
ii. Air compressor	25-50
iii. Pump	25-90
iv. Internal combustion engine	65-120
v. Air conditioning & refrigeration condenser	30-45

6.5.3 Utilization of Waste Heat

Medium- to high-temperature exhaust gases can be used to preheat the combustion air for:

(a) Boilers using air-preheaters
(b) Furnaces using recuperators
(c) Ovens using recuperators
(d) Gas turbines using regenerators

- Low- to medium-temperature exhaust gases can be used to preheat boiler feedwater or boiler make-up water using economizers.

- Exhaust gases and cooling water from condenser can be used to preheat liquid and/or solid feedstocks in an industrial process.

- Exhaust gases can be used to generate steam in waste heat boilers.

- Waste heat may be transferred to liquid or gaseous process units directly through pipes and ducts or indirectly through a secondary fluid such as steam or oil.

6.5.4 Waste Heat Recovery Equipment

The principal methods of reclaiming waste heat in an industrial plant make use of heat-exchangers. The heat exchanger is a system which separates the stream containing waste heat and the medium which is to absorb it, but allows the flow of heat across the separation boundaries.

Heat exchangers are characterized as single or multipass, gas-to-gas, liquid-to-gas, liquid-to-liquid, evaporator, condenser, parallel flow, counter flow, or cross flow. Industrial heat exchangers have many pseudonyms. They are sometimes called recuperators, regenerators, waste heat steam generators, condensers, heat wheels, temperature and moisture exchangers, etc. They all perform one basic function of transferring heat. Details of some of these pieces of equipment in brief are given below.

Recuperator. A recuperator is a heat exchanger which recovers waste heat from the exhaust gases of a furnace to heat the incoming air for combustion. This is the name used in both steel and glassmaking industries. The heat exchanger performing the same function in the steam generator of an electric power plant is termed an air preheater whereas in the case of a gas turbine plant, a regenerator.

Metallic Radiation Recuperator. The simplest configuration for a heat exchanger is the metallic radiation recuperator which consists of two concentric lengths of metal tubing as shown in Figure 1. The inner tube carries the hot gases which the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber. This particular recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of inner tube takes place by radiative heat transfer. The cold air in the annulus, however, is almost transparent to infrared radiation so that only convective heat transfer takes place to the incoming air.

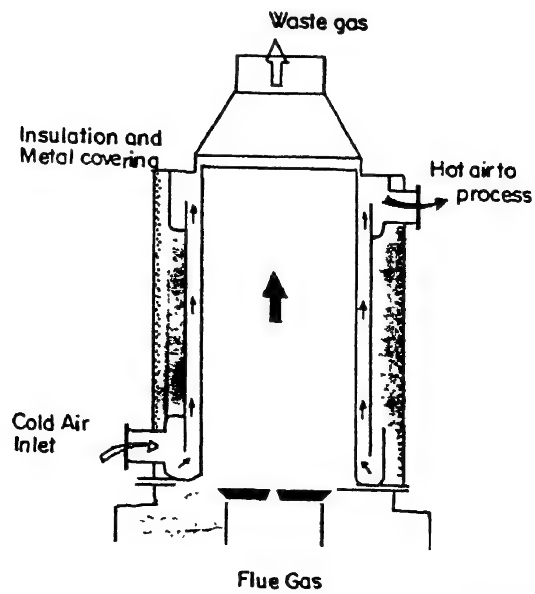

Figure 1: Metallic radiation recuperator

Convective Recuperator. A second common configuration is called the tube type convective recuperator. As seen in the schematic diagram of Figure 2, the hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes. Shell and tube-type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases.

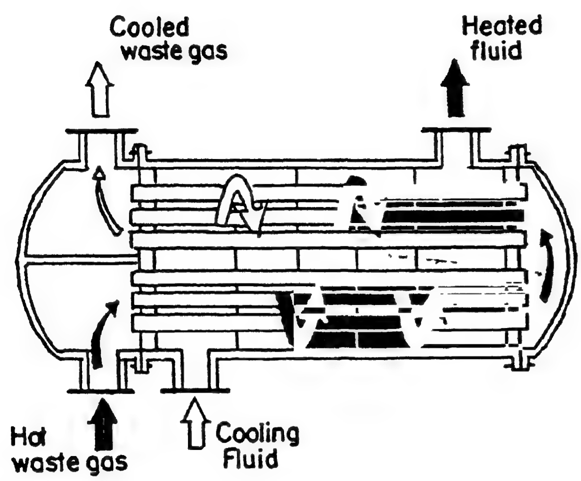

Figure 2: Convective recuperator

Ceramic Recuperators. The principal limitation on the heat recovery of metallic recuperators is the reduced life of the liner at inlet temperatures exceeding 1100°C. In order to overcome the temperature limitations of metal recuperators, ceramic tube recuperators have been developed, whose material allows operation on the gas side to 1500°C and on the preheated air side to 1200°C on an experimental basis, and to 800°C on a more or less practical basis. It consists of various kinds of short silicon carbide tubes which can be joined by flexible seals located in the air headers. This type of design, illustrated in Figure 3, maintains the seals at comparatively low temperature and has reduced the seal leak rates to a few per cent. Ceramic construction offers a better thermal shock resistance and resistance to high temperature corrosion particularly corrosion arising from sulphur and vanadium present in the flue gases.

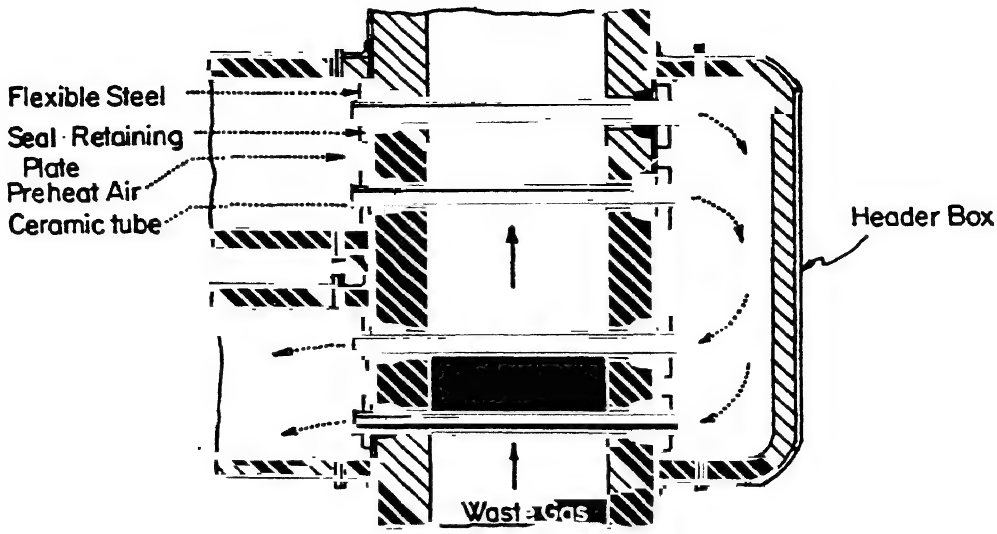

Figure 3: Ceramic recuperator

Tube-within-Tube Recuperator. An alternative arrangement to the convective type recuperator, in which the cold combustion air is heated in a bank of parallel vertical tubes, which extend into the flue gas stream, is shown schematically in Figure 4. The advantage claimed for this arrangement is the ease of replacing individual tubes, which can be done during full capacity furnace operation. This minimizes cost, inconvenience and possible furnace damage due to shutdown forced by recuperator failure.

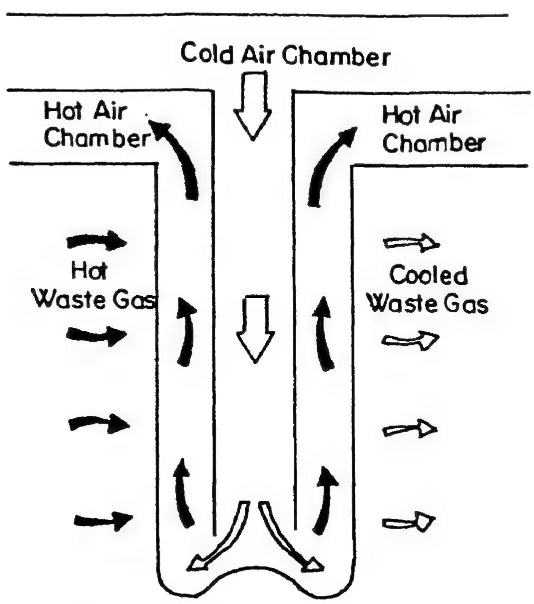

Figure 4: Tube-within-tube recuperator

Radiation and Convective Tube Recuperator. For maximum effectiveness of heat transfer, combinations of radiation type and convective type recuperators are used with the convective type always following the high temperature radiation type recuperator. A scematic arrangement is shown in Figure 5.

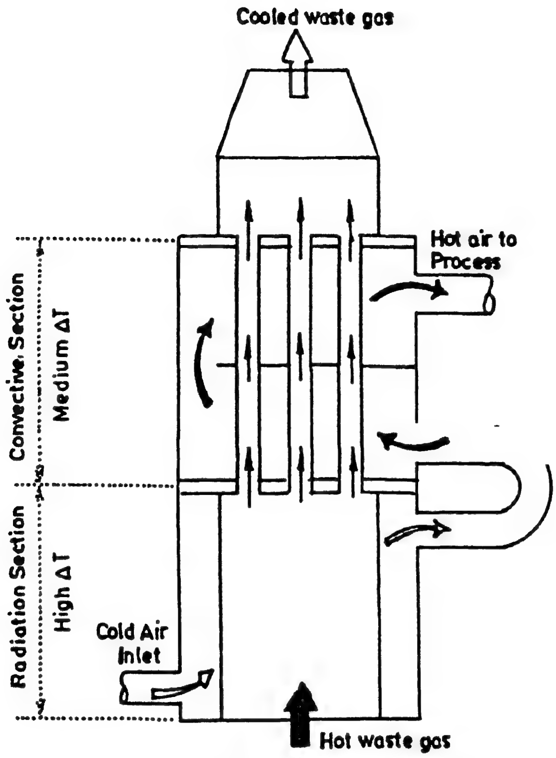

Figure 5: Radiation and convective type recuperator

Regenerators. Regenerator is a form of heat exchanger used for recovery of heat at low to high temperature levels. In a regenerator, the same portion of a heat exchanger goes through heating and cooling in an alternate cyclic mode.

In glass and steel industries, the word regenerator refers two chambers of brick checkerwork which alternately absorb heat from the exhaust gases and then give up part of that heat to the incoming air. The flow of flue gas and air are periodically reversed by valves so that one chamber of regenerator is being heated by the products of combustion while the other is being cooled by the incoming air. Regenerators application is primarily in glass melt tanks and in open hearth steel furnaces.

Heat Wheels. A rotary regenerator (also called an air preheater or a heat wheel) as shown in Figure 6, is a sizeable porous disk, fabricated from a material having a fairly high heat capacity, which rotates between two side-by-side ducts-one a cold gas duct, and the other a hot gas duct. As the disk rotates slowly, sensible heat

(and in some cases, moisture containing latent heat) is transferred to the disk by the hot air and later from the disk to the cold air. The overall efficiency of sensible heat transfer can be as high as 85 per cent.

Heat wheels are finding increasing use for process heat recovery in low and moderate temperature environment. Typical applications would be curing or drying ovens, and air preheaters in all sizes for industrial and utility boilers.

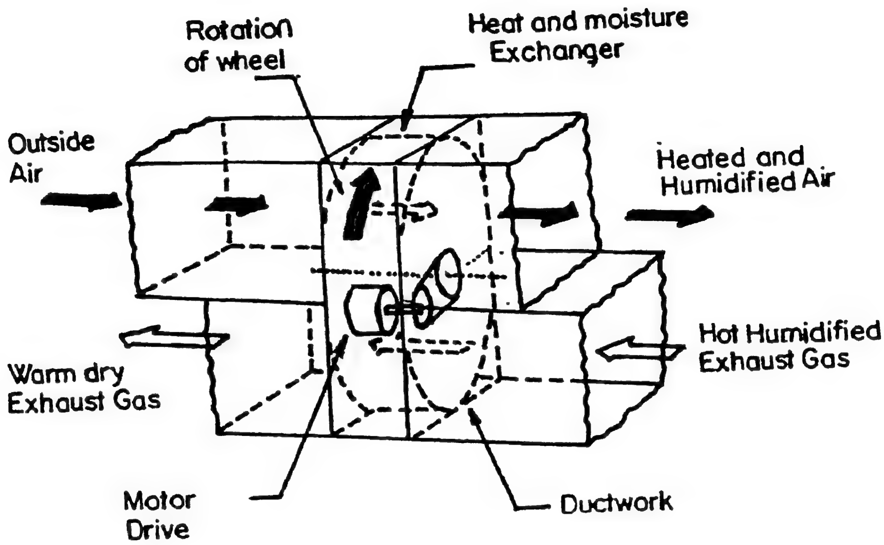

Figure 6: Heat wheel

Air Preheaters. Passive gas-to-gas regenerators, sometimes called air preheaters, are available for applications which cannot tolerate any cross contamination. They are constructed of alternate channels (see Fig.7) which put the flows of the heating and the heated gases in close contact with each other, separated only by a thin wall of conductive metal. An advantage, besides the absence of cross-contamination, is the decreased mechanical complexity since no drive mechanism is required. However, it becomes more difficult to achieve temperature control with the passive regeneration. Gas-to-gas regenerators are used for recovering heat from exhaust gases to heat other gases in the low- to medium-temperature range. A list of typical applications is as follows:

- Heat and moisture recovery from building heating, ventilation systems, moist rooms and swimming pools.

- Recovery of heat and water from wet industrial processes

- Heat recovery from baking, drying and curing ovens

- Heat recovery from steam boilers, and gas turbine exhausts.

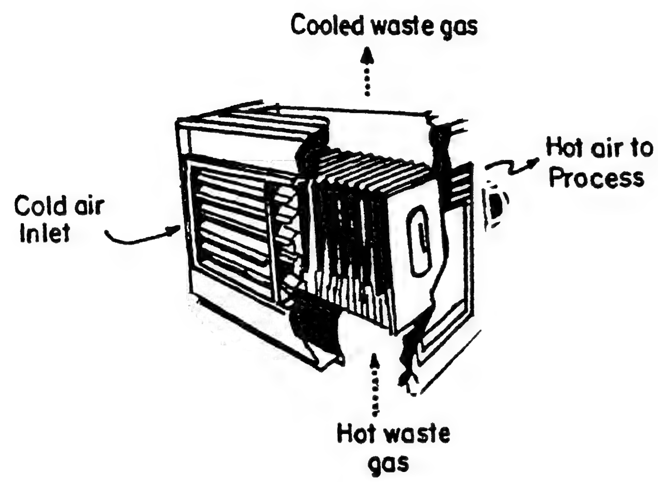

Figure 7: Air preheater

Heat-Pipe Exchangers. The heat pipe is a heat transfer element having high efficiency and compact size. In use, it operates as a passive gas-to-gas finned tube regenerator, as shown in Figures 8 and 9.

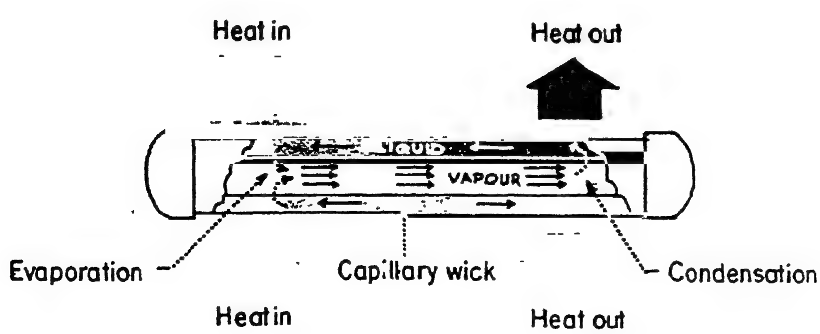

Figure 8 : Principle of heat transfer in Heat pipe exchanger

In Fig. 9 the heat transfer mechanism is shown. Hot exhaust gases evaporate the entrained fluid and the vapours so formed carry the latent heat of vaporization to the cold end of the heat pipe located in the cold gas duct. After the transfer of heat to the cold gas, condensed liquid is then carried back to the hot end where it is recycled. The heat pipe is compact and efficient because (1) the finned-tube bundle is a good configuration for convective heat transfer (2) the evaporative condensing cycle is a highly efficient way of transferring heat internally.

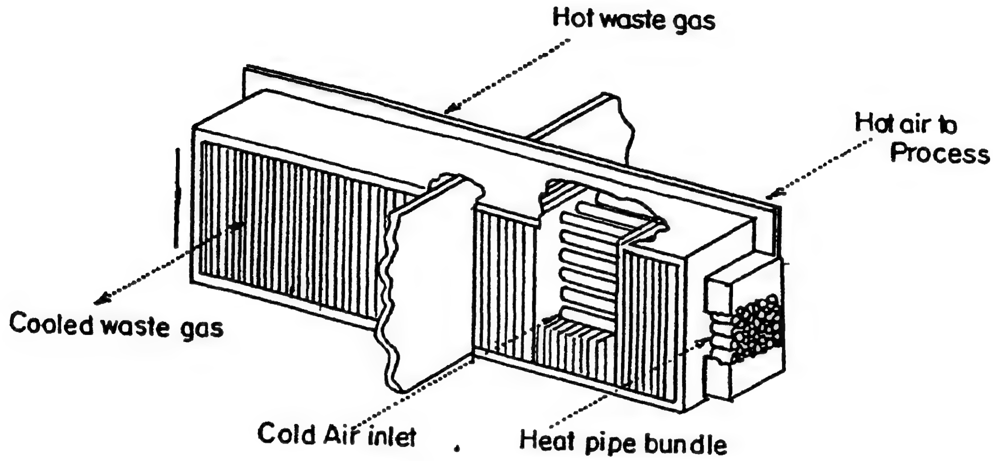

Fig.9: Heat pipe heat exchanger

Fin - Tube Heat Exchanger. When waste heat in exhaust gases is recovered for heating liquids for different purposes, the finned tube heat exchanger is generally used. Round tubes are connected together in bundles to contain the heated liquid and fins are welded to provide additional surface area for removing the waste heat in the gases. Figure 10 shows the usual arrangements for the finned-tube exchanger positioned in a duct. This particular type of application is more commonly known as an economizer.

Fin-tube heat exchangers are used to recover waste heat in the low-to-medium-temperature range from exhaust gases for heating liquids. Typical applications include domestic hot water heating, heating boiler feedwater, hot water space heating, absorption type refrigeration or air-conditioning, and heating process liquids.

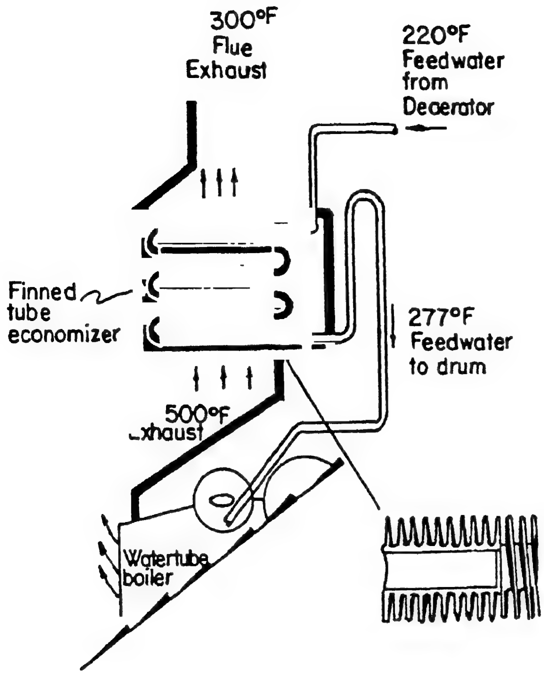

Figure 10 : Fin-tube heat exchanger

Waste Heat Boiler. Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases pass over a number of parallel tubes containing water. The water is vaporized in the tubes and collected in a steam drum from which it is drawn off for use as heating or processing steam. Figure 11 indicates one arrangement that is used, where the exhaust gases pass over the water tube twice before they are exhausted to the air.

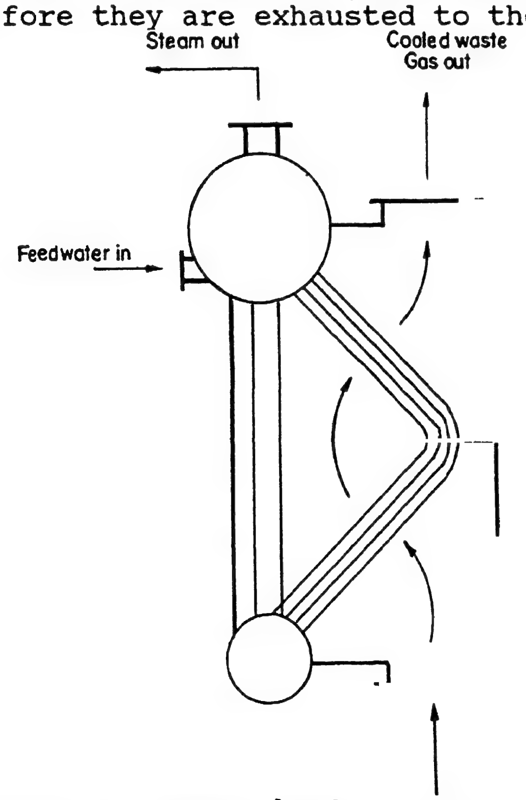

Figure 11 : Waste heat recovery boiler

The diagram shows a water drum, a set of tubes over which the hot gases make a double pass, and a steam drum which collects the steam above the water surface. The pressure and rate of steam so produced depend on the temperature, flow rate of exhaust gases and the efficiency of the boiler.

Typical applications include recovery of heat from exhausts of gas turbines, reciprocating engines, incinerators and furnaces.

Projects

(1) Identify sources of waste heat in your plant/ Workshop and categorize them according to temperature ranges. Quantify total heat recoverable under practical conditions.

(2) For the largest source of waste heat, design a waste heat recovery system including specifications for an appropriate type of heat exchanger. Identify areas where the waste heat could be utilized.

(3) Work out the techno-economic feasibility of the system designed as per (2) above.

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(2) Goldstick, R.J. and Thumann, Albert, Waste heat Recovery Handbook, The Fairmont Press, Inc., Atlanta, U.S.A. (1983)

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Section 6: Heat Pump

6.6.1 Introduction

A heat pump can be considered simply as a heat engine in reverse. A heat engine removes heat from a high temperature source and discharges heat to a low temperature sink and in doing so can deliver work. A heat pump requires a work input to remove heat from a low temperature source and deliver it to a higher temperature. It is interesting to note that the energy required by heat pump to produce heat is less than the energy required for direct heating.

The common place domestic refrigerator is a form of heat pump. It extracts heat from food and it heats the room in which it is located. Although it is not designed to provide heat, it nevertheless does so. In contrast, a heat pump is specially designed to provide heating, but at the same time, must provide cooling.

Very often the heat source is a waste heat stream and in many situations, particularly for space heating, the ground heat or ambient air may be used. To increase the temperature, energy in the form of heat or mechanical energy has to be supplied. However, this represents a small portion of the heat delivered.

6.6.2 Thermodynamic Model of Heat Pump and Carnot Cycle

The cycle shown in Figure 1 is for a heat pump. Heat is delivered isothermally at T_H and received isothermally at T_L. Expansion and compression are achieved isentropically and the balance of work required is delivered by an external primemover.

By using the definition of entropy and the laws of thermodynamics it can be shown that the Carnot Coefficient of performance C.O.P. of a refrigeration system is given by

$$\text{C.O.P refrigeration system} = \frac{T_L}{T_H - T_L}$$

$$\text{C.O.P. (heat pump)} = \frac{T_H}{T_H - T_L} = \frac{T_H - T_L + T_L}{T_H - T_L}$$

or we can conclude that

$$\text{C.O.P. heat pump} = \text{C.O.P. refrigeration} + 1$$

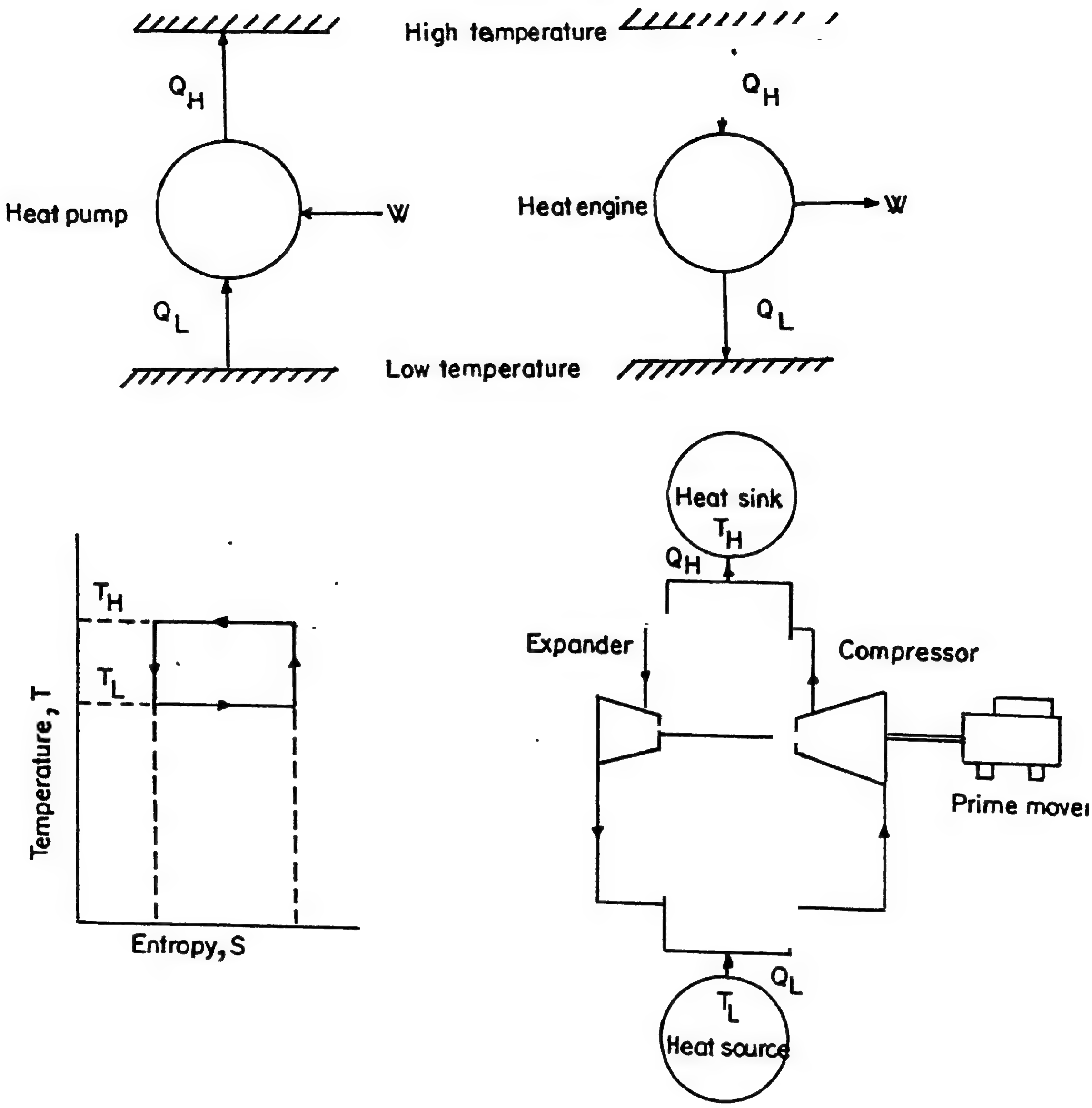
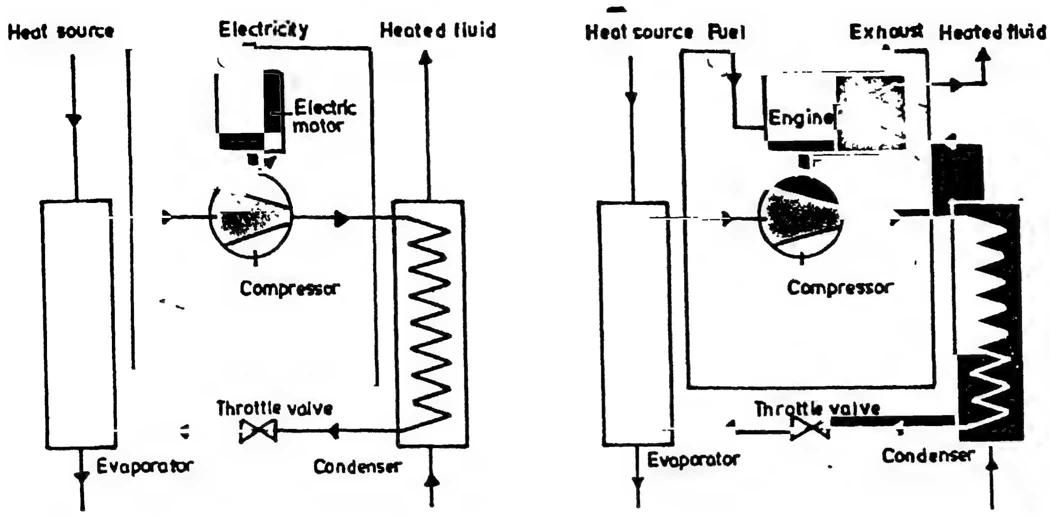


Figure 1: Thermodynamic model and cycle for heat pump

6.6.3 Vapour Compression Cycle Heat Pump

As clearly shown in Figure 2, heat is extracted from the heat source in an evaporator isothermally, and the refrigerant in vapour form goes to the compressor where high pressure and higher temperature are achieved. Heat is transferred from the condenser isothermally as vapours condense, and the refrigerant changes to liquid form. Liquid refrigerant then expands in an expansion device (isentropically) and goes to the evaporator at low temperature and pressure. This cycle repeats itself as explained above.



Vapour compression cycle pump

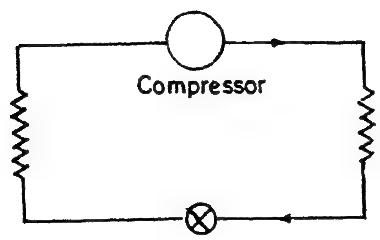


Figure 2: Vapour compression cycle heat pump

The following are the components in a vapour compression heat pump:

a) Primemover may be an electric motor or an engine used to drive the compressor

b) Compressor which is used to compress dry vapours

c) Evaporator used to extract heat from the heat source

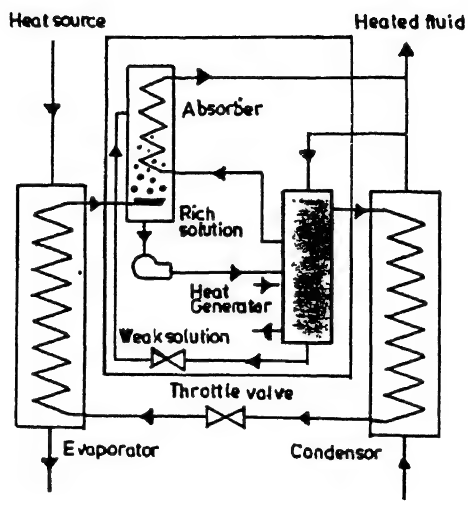
d) Condenser which provides the heat output

e) Throttle valve used for expansion

6.6.4 Absorption Cycle

As shown in Figure 3, an absorption heat pump contains an evaporator and condenser which operate in exactly the same way as for the vapour compression cycle. In the absorption cycle, however, there is a secondary circuit around which a liquid absorbent or solvent flows. The evaporated refrigerant vapour is absorbed by the solvent at low pressure, and there is a net transfer of heat in this process. The concentrated solution from the absorber

is pumped to the heat generator whereby the pressure is raised to that of the generator. High pressure refrigerant vapour is then produced by the addition of heat to the mixture in the generator. Because the liquid solvent/ refrigerant mixture is virtually incompressible, the work of the pump is genuinely negligible, and the primary energy source is the heat required at the generator which is always the hottest part of the cycle. The heat liberated from the absorber can be added to the heat required at the generator which is always the hottest part of the cycle. The heat liberated from the absorber can be added to the heat from the condenser so that it can be made certain that as a heat pump the C.O.P is always greater than one.



Absorption cycle heat pump

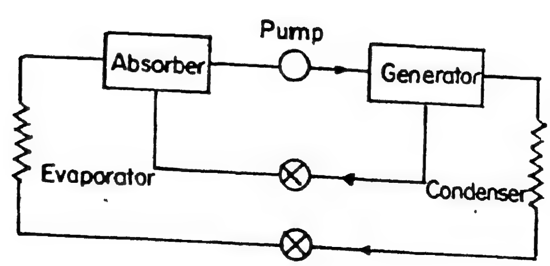


Figure 3: Vapour absorption system

6.6.5 Comparison of Vapour Compression Cycle and Vapour Absorption Cycle

Absorption heat pumps have a number of advantages when compared with vapour compression cycle units as listed below:

a) the heat pump is driven by heat at different temperature levels and thus various fuels/heat sources may be used. Normally a waste heat source is used in a vapour absorption cycle.

b) It has fewer moving parts. The only moving parts are in the pump.

c) It has low maintenance requirement.

d) The heat pump produces no noise.

e) It is expected that in future the absorption heat pump will be able to reach higher temperature.

6.6.6 Vapour Recompression Cycle Heat Pump

Technical Background

A mechanical vapour recompression system (MVRS) is a system that converts waste heat, low pressure steam or vapour into high pressure steam or vapour for industrial process use. This is a form of heat pump. If MVRS is used for generating high pressure steam, it is also called steam heat pump.

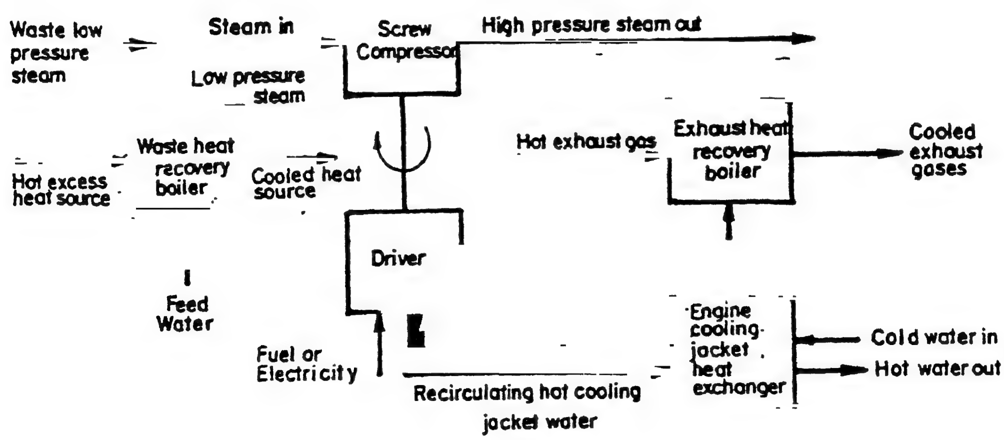


Figure 4: Vapour recompression system

The concept of MVRS is simple. Low-pressure steam or vapour, directly available or generated from another source, is mechanically recompressed to raise the temperature and pressure to a useful process level. Since the latent heat of vapourization is recycled, the energy needed to recompress the steam is only a small fraction of the energy necessary to generate steam at the same pressure in a boiler. Therefore substantial energy saving results.

A simple MVRS system is shown in Figure 4. Low-pressure steam flowing from the exhaust of a turbine and/or a waste heat recovery boiler is compressed in a screw compressor. The compressor can be coupled to a variety of drives such as a natural gas or diesel engine, a gas turbine, a steam turbine and an electric motor depending upon the specific application needs. The high-pressure steam from the compressor is used for various process applications. Hot exhaust gases from the driver are utilized in an exhaust heat recovery boiler. The heat in the walls of the engine jacket is also dissipated by circulating cold water through the engine cooling jacket heat exchanger, thus producing hot water for certain specific uses.

The system savings are determined by pressure ratio, choice of drives, and relative fuel costs. The compressor power depends upon the pressure ratio. The energy needed can be as low as 10 per cent of the total fuel energy needed in the boiler to produce the same steam conditions.

6.6.7 Heat Pump Research in India

The National Chemical Laboratory (NCL), Pune has made pioneering efforts in the area of heat pump research in India through an international collaboration with the university of Salford, U.K. since 1980. Under this programme, British heat pump units have been installed at NCL. The aim of the project is to promote the use of heat pumps in Indian industry for energy saving and recycling. Based on the pilot operation of a methanol-water distillation column using an external mechanical vapour compression heat pump at the University of Salford, NCL has designed and developed an ethanol - water distillation column.

NCL offers a comprehensive service to industry to identify the potential area of application of heat pumps, prepare techno-economic reports, assist in the selection of heat pumps and conduct in-house training programme on heat pump technology.

6.6.8 Current Status of Technology and Manufacturing of Heat Pumps in India

In India, a few absorption chillers using ammonia-water have been installed in fertilizer plants to produce chilling in the temperature range of -30^{o} to -10^{o}C using low-pressure steam, hot water or hot process gas. A few other units have been installed in other types of industrial units. Absorption chillers using water and lithium bromide are commercially available, mostly from Japan.

For heat pump applications, packaged heat pumps are being marketed mostly by Japanese companies for two temperature ranges. Absorption heat pumps are available for applications up to 90^{o}C. A manufacturer in Calcutta (ASCU India Limited) makes heat pumps-based dehumidifiers for application in timber drying.

List of Symbols

Q_H: Heat Added

Q_L: Heat Rejected

W: Work

T: Temperature

C.O.P.: Coefficient of Performance

P: Pressure

H: High

L: Low

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Section 7: Diesel Generators

6.7.1 Introduction

Electric power shortage is widespread in our country, crippling normal operations of industrial units and reducing industrial productivity. Industries are thus forced to install captive diesel generator (DG) sets to augment supply and in many instances provide for the units' total power requirements. The number of captive diesel generator units installed has shown a rapid increase in the recent past, reflecting the deteriorating utility power supply situation in many states.

Almost all of the presently installed DG sets are designed to operate on distillate fuels, viz., HSD/LDO (High Speed Diesel/Light Diesel Oil). However, a few new sets being installed, will be operating on Heavy Petroleum Stock (HPS) and Heavy Residual Fuel Oil. The existing DG sets consume distillate fuels which are scarce in the country. Moreover, DG sets being critical equipment for the plant operation, are run for long periods. This leads to substantial costs being associated with the operation and maintenance of the DG sets. Hence, it is vital that adequate attention be provided right from inception, on selection, installation, operation and maintenance of these sets. Training should also be provided to the engine-room operators to appreciate the importance of the DG sets.

The note discusses the several issues related to the proper operation and maintenance of DG sets, leading to better performance efficiency, and fuel conservation.

Factors which affect the operation efficiency and fuel consumption in DG sets are listed below. Details explaining the importance of each of them is given. Possible methods and techniques of improving DG set efficiency are also provided. These factors could be classified as:

- Extent of Loading
- Proper Instrumentation
- Lube Oil Conservation
- Fuel Additives
- Waste Heat Recovery
- Maintenance procedures

6.7.2 Extent of Loading

The extent of loading on diesel generators is a very important parameter in determining the efficiency of engines. Almost all diesel engines have low efficiencies at loads below 50 per cent. A DG set may often not be made to generate to its full rated capacity. If this happens, the fuel consumption per kWh generated increases.

The increase will depend upon (i) the ratio of actual output to rated capacity; and (ii) design and capacity rating of the DG set. Figure 1 illustrates the observations made in a field test to study the change in fuel consumption of a DG set at different loads. Table 1 gives a comparison between the recommended and actual specific fuel consumption for DG sets of different capacities. The manufacturers' specifications of part load fuel consumption for different DG sets are provided in Table 2. Note the higher fuel consumption, when the sets operate at lower loads. At part loads at or below 50 per cent, the fuel consumption increases with increasing capacity of DG sets, and are higher than those of small DG sets.

However, there are instances where a DG set is unable to be loaded to its full capacity. This could be due to:

- Overheating of the engines

  It is recommended that the cooling circuit be maintained well, and water quality be tested to avoid scale deposition.

- Poor response of governors

  Due to the inertia and sluggishness of mechanical governors, DG sets are unable to respond to load changes. It is essential that the governor mechanism is maintained well.

Many operators experience the problem of not being able to detect higher fuel consumption or changes in parameters, due to faulty or improper instrumentation. It is, hence, absolutely essential to provide individual flow meters and other indicating instruments to detect the problem early and rectify them in time. Several plants do not maintain accurate records of HSD consumption in the DG sets. Only data relating to HSD purchased is available. No fuel management programme can take off unless the database is complete and sound.

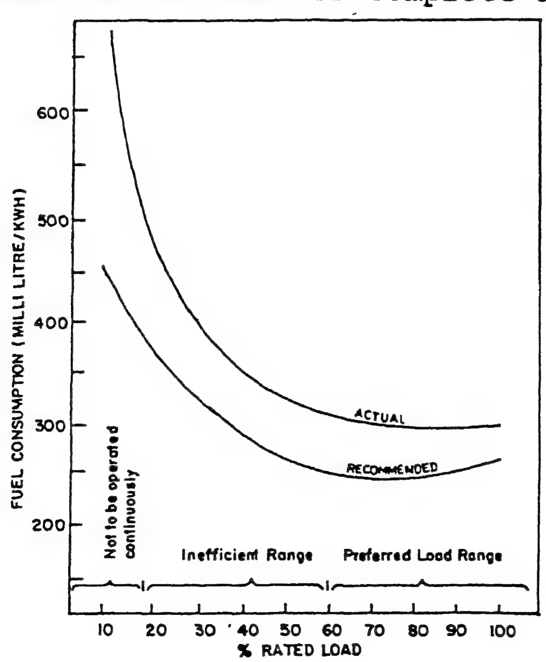

Fig.1: Variable load characteristics of diesel gen. sets

Table 1

Specific Fuel Consumption of HSD, Recommended Vs. Actual

Rating kVA	Recommended kWh/L	Actual* kWh/L
1450	3.84	3.2
1100	3.88	2.7
625	3.73	2.7
608	3.50	3.47
550	3.50	2.64
500	3.84	2.64
400	3.69	2.26
310	3.30	3.28-2.96
250	3.20	2.7
180	3.07	2.8-2
175	3.0	2.7
166	3.0	2.55
160	3.0	2.5
120	3.0	2.38

* Actual kWh/L figures are for specific DG sets. These values cannot be applied to DG sets of same size of other makes and models. These values are provided only as examples.

Table 2

Implications of Part-Load Conditions on Diesel Consumption

Rated Capacity kVA	L/kWh of HSD for Various Loading Conditions, %			
	100	75	50	25
<100	0.2341	0.2404	0.2496	0.2617
320	0.2311	0.2388	0.2542	0.2750
1000	0.2301	0.2378	0.2531	0.2789

Source: Personal Communication, Kirloskar Cummins Ltd., New Delhi.

* Applicable only for Kirloskar Cummins DG sets

6.7.3 Lube Oil Conservation

Lubricating oils are consumed in large quantities by DG sets. An estimate by the Petroleum Conservation Research Association (PCRA) shows that around 10,000 tonnes of engine oils were used in 1986-87 for consumption in DG sets alone. Although the quantity of lubes used is much less compared to the HSD consumption, the price of lubes is nearly thrice as that of HSD. Therefore, lube oil conservation in DG sets is important. The consumption of lubes depends largely on the number of hours for which a DG set is operated, the speed of the engine and its size. Lubes have to be changed after a specified number of hours of operations.

Lubricating oil consumption is either due to top-up or oil change. Factors which affect the top-up and oil change are given below:

Top-up

The top-up oil consumption will largely depend upon:

- engine design - piston rings, clearances in valves, guides, etc.

- engine operating condition - speed and load, frequent start/stops

It is necessary to avoid overlubrication during top-up, as it leads to excessive viscous drag, and deposition of scales.

Oil Change

The useful life of lubricating oils is limited by the process of degradation and contamination. Degradation refers to an irreversible change in oil quality, e.g., oxidation. Contamination refers to a condition, where external unwanted agents have infiltrated into the oil.

Oil in service deteriorates due to degradation and contamination. At this stage the oil charge has to be replaced by fresh charge. The general practice being followed is to drain the oil at predetermined intervals. The interval is specified by the equipment supplier as number of hours of operation between oil change. The oil change intervals for different DG sets (as examples) are given in Table 3.

Table 3

Lube Oil Drain Intervals for Different DG Sets (Examples)

Brand	Installed Capacity (kW)	Recommended Oil Drain Interval in Hours of Operation
SKL	500	1000
SKODA	400	500
RUSSIAN	35	500
CUMMINS	400	250

Table 4

Tests Required for DG Set Engine Oils

Test	Test Method	
Kinematic Viscosity at 40°C	ASTM	D445
Kinematic Viscosity at 100°C	ASTM	D445
Viscosity Index	ASTM	D2270
Total Acid Number	ASTM	D974
Total Base Number	ASTM	D664/2896
Water	ASTM	D95
Pentane/Benzene insolubles	ASTM	D893
Flash point	ASTM	D92

Source: Workshop on Diesel Conservation in Captive Power Generation (Background Paper), Confederation of Engineering Industry, New Delhi, September 24,1987.

These specified intervals are based on the worst possible operating conditions and hence, provide a safe limit. If a user operates under less severe conditions and better maintenance practices, he is likely to discard oils when they are still good enough for use. Therefore, a scope exists for conservation of engine oil, if the drain period intervals are optimized based on operating conditions or oil is drained on a condition basis.

To arrive at an optimum drain period, test the oil for its key properties. These properties, along with the test methods are shown in Table 4. To implement these physico-chemical tests, a small laboratory facility may be required. On the basis of the results of the laboratory tests, decide whether to reduce, extend or keep the same drain interval. The cost of the facilities will be paid back within a short time from the savings accrued due to longer oil drain periods.

6.7.4 Fuel Additives

Generally, fuel additives are used only when a specific problem exists and when other conventional solutions have been exhausted. Fuel additives have been mainly used in boilers to improve combustion efficiency, inhibit high temperature corrosion, avoid cold end corrosion and formation of deposits. It is necessary to understand clearly both the benefits and potential disadvantages of the additives under consideration.

With special reference to fuel additives for improving combustion efficiency in DG sets, it may be noted that results of tests conducted by PCRA reveal that out of thirty additive suppliers, who all claim improvements in combustion efficiency, only one brand of additive after use has shown a slight improvement in the engine efficiency. The improvement is marginal, and efficiency of the DG set has increased by 2 per cent, in contrast to the manufacturers claim of 10-15 per cent. Almost in all instances, the additives are not cost effective.

Tests are still in progress to confirm the observed increase in efficiency. The effects of long-term use of an additive on the engine parts have not yet been studied; additives have to be checked for corrosion and fouling possibilities.

6.7.5 Waste Heat Recovery

DG sets operate in an efficiency range of 30-40 per cent. This shows that of the 100 per cent energy given by the fuel, only 30-40 per cent is converted to electricity.

The rest is lost as waste heat. The major sources of waste heat in a DG set are:

- Engine exhaust gases
- Jacket cooling water
- Lube oil cooling circuit

Various waste heat recovery equipment are available for the recovery of the otherwise wasted energy. The recovered waste heat could be used as a heat source in a few applications. Some of the possible applications are listed below:

- Preheat combustion air for heaters/furnaces near by
- Generate hot water for process
- Waste heat boiler for steam generation
- Vapour absorption refrigeration system for cooling
- Preheating stock for furnaces

Waste heat recovery schemes are viable only when large quantities of hot exhaust gases are available and on a continuous basis, i.e., large capacity sets or a cluster of smaller capacity DG sets. However, it must be noted that these schemes will have a reasonable payback only if the DG sets are being run for a larger part of the year.

6.7.6 Maintenance Procedure

Strict adherence to recommended maintenance practices will ensure efficient operation of the DG sets, as well as save fuel. A checklist of the important maintenance activities for DG set is provided below:

General

- Check for compression pressures and attend to stuck piston rings, leaky valves, excessive liner wear and ring wear, etc. promptly.

- Meet manufacturer's norms regarding parameters like cooling water temperatures, back pressure, flow rate, etc.

- Ensure cleanliness in the generator room.

Fuel Injectors

- Check injectors once in three weeks, for leakage and spray pattern

Exhaust Valves

- Frequency of overhaul depends on exhaust gas temperature and impurities in air and fuel

Starting Valve

- Ensure proper closing of the valve after start. Drain the starting air tank regularly to prevent corrosion and leakage of starting valve seat

Pistons/Piston Rings

- Ensure proper cooling and lubrication; replace rings in time. Clear lube oil passages.

Heat Exchangers

Clean once in every 500 hours of operation, if hard water is in use. Water pH to be between 7-8.

Turbo Charger

Breather to be cleaned externally once in an hour, an internal surface once in 100 hours of operation.

Fuel and Lube Economy

Appendix 1 provides operating and maintenance tips for fuel and lube efficiency in DG sets.

6.7.7 Conclusion

A systematic maintenance of DG sets would ensure efficient operation of these sets and fuel efficiency. In cases where old DG sets are used, it would be worthwhile evaluating the costs and benefits of newer sets which are much more energy efficient. In the existing sets, lube oil conservation would be attractive, which can be achieved through proper measurement of an various characteristics of lube oil to determine change frequency need.

Reference

- Confederation of Engineering Industry (1987), Background Paper, Workshop on, "Diesel Conservation in Captive Power Generation", New Delhi.

- Waste Heat Management Guidebook, NBS Handbook 121 Energy Administration (1977), Washington, U.S.A.

Appendix 1

Diesel Generator Sets
Operating Tips for Fuel and Lube Efficiency

1. Select proper fuel. If injection system can tolerate more viscous fuels like LDO, furnace oil or other residual fuels like LSHS or HPS, go for higher viscosity fuels.

2. Ensure proper storage and handling of fuel. Dirt and contamination will make the fuel go off specification.

3. Load the DG set above 50 per cent for large D.G. sets, and above 60 per cent for small sets.

4. Ensure proper fuel injection, correct viscosity and temperature, timing proper mechanical condition of components, and prevent lube contamination.

5. Select proper lubricant. Monitor lubricant condition through regular sampling and analysis of used oil. Ensure proper lubricant cooling and consumption. **(Thicker oil cause 2 per cent excess fuel consumption).**

6. Externally clean the air filters regularly, to ensure proper filteration and cleanliness of intake air.

7. Avoid leakages of fuel oil and lube oil, even though they may be of minor nature. They are a major cause for higher fuel and lube consumption.

8. Normally, engine oils of SAE 40 grades are used in D.G. sets, unless otherwise recommended by the manufacturers. Use of multigrade and higher performance level oils with high detergency, alkalinity reserve and antiwear properties help in both lube and fuel conservation in addition to improving engine mechanical efficiency.

9. Check compression pressure regularly if provision exists. Attend to stuck piston rings, leaky valves, clogged ports, excessive liner and ring wear, etc. promptly.

10. Insulate exhaust piping to reduce air temperature inside the generator room as the higher intake air temperature increases the specific fuel consumption and reduces engine output, **(Engine output reduces by about 5 per cent for 10°C rise in intake temperature)**

11. Avoid exhaust gas temperature above 450°C. High exhaust temperatures due to overload and restricted air supply, could lead to lower fuel efficiency as well as fouling of turbo-chargers.

12. Avoid over lubrication to prevent deposits inside the engine and on the turbo-charger blades.

13. Maintain the cooling circuit system and clean heat exchangers regularly. Meet manufacturer's norms on cooling water temperature, back pressure, flow rate, quality etc.

14. Adopt preventive or preferably predictive mainteance programmes.

15. Attempt waste heat recovery, if technically and economically viable.

Diesel Generator Sets Measures for Diesel Engine Lubrication Oil Conservation

1. Improve air filtration

2. Reduce fuel dilution by

   a. ensuring proper atomization
   b. having correct engine temperature
   c. having proper air-fuel ratio
   d. ensuring proper crankcase venting
   e. eliminating worn out rings and cylinder liners

3. Check insolubles build-up in oil by using proper air, oil and fuel filters

4. Reduce oil loss by proper clearance between valve stem and guide

5. Reduce oil loss piston by

   a. reducing carbon deposits on top land
   b. avoiding bore polishing and glazing
   c. attending to ring wear

6. Provide by-pass purification system or remove insolubles by centrifuging

7. Use long drain oils with improved air and oil filters

8. Monitor TBN values more closely where high sulphur diesel is used

9. Switch on to multigrade oils for oil as well as fuel economy

10. Check for leaks in the lubrication system and attend to them promptly

11. Change oil on condition basis and not on the thumb rule recommended by oil companies or engine builders. Field oil testing systems are readily available in the country

12. Oil never deteriorates. It goes off specs temporarily. The drained oil can be re-refined and brought to proper level by appropriate re-refining and reclamation techniques. For further details on refining, consult PCRA booklet titled 'How to Conserve Lubes' (through recycling). For any further information on this, please contact PCRA, New Delhi.

Note: Oil refers to engine lubricant and fuel refers to diesel oil.

* PCRA - Petroleum Conservation Research Association.

Section 8: Compressed Air System

6.8.1. Introduction

Compressed air is widely used in industries as a source of power because it is convenient, reliable and safe. Compressed air is an expensive power source, for a given power, the cost of compressed air is 7-10 times the cost of electricity. In practice, compressed air generation consumes anywhere between 10-50 per cent of the total electricity in an industrial unit.

Energy can be lost at almost every stage of a compressed air system. However, steps can be taken at every stage of the system from the air intake through the compressor and after-cooler, which will ensure that a supply of compressed air is delivered at the current rate and conditions of pressure, temperature and moisture content for the lowest energy requirement and running cost.

6.8.2 Air Intake

The basic requirement at the air intake to a compressor is that an adequate supply of clean, cool and dry air is admitted for compression. Intake air for compressor should be at the lowest temperature available. Preferably air should be taken from outside the compressor room because its temperature will be lower. Ducting between air intake and the compressor should be short, straight and of sufficiently large diameter.

Every $6^{o}C$ drop in temperature in the intake air will save about 2 per cent of electrical power for delivery of the same quantity of air.

6.8.3 Compressor

The compressor is the heart of the system and it represents the main energy input to the system. Proper care in the selection of the compressor and a proper maintenance procedure and in particular elimination of waste will help provide significant energy cost reduction.

The choice of efficient compressor is based on consultation with the compressor manufacturer or supplier on exact values of specific power consumption. The location of compressors should be such that air distribution losses are kept to a minimum.

Table 1 gives the comparative advantages and disadvantages of reciprocating, screw and centrifugal air compressors.

Table 1

Technical Comparison Between
Reciprocating, Screw & Integral Geared Centrifugals

Reciprocating	Screw	Centrifugal
Available as lubricated or oil-free.	Available only as lubricated in India. However, imported dry screw compressors are available as oil-free.	By the nature of the design it is 100 % oil-free. Available only as imported equipment at present.
Oil-Free Reciprocating	Oil-Free Dry Screw	Oil-Free Dry Turbos
Oil-free air is available due to the use of glass filled teflon piston rings. Piston rings have a short life and are subject to frequent replacement.	Stainless steel rings held in special retainers which are fitted to the shaft are used. It is believed that carbon rings are used allowing the possibility of draining oil into the system.	Non-contact air and oil labyrinth seals and an atmospheric air space between the two seals is used. The oil seals, seal, air space and positively pressurised air seal are four lines of defense to prevent oil from entering the compression section. This ensures 100 % oil-free air.
An expensive foundation required to support the static and dynamic load generated in the compressor.	Only static weight bearing foundation is necessary. No major foundation is necessary if compressor is skid-mounted.	Only static bearing foundation is necessary.
For capacities beyond a 1000 cfm, the size of the unit becomes very large using up valuable space.	Unit is compact.	Unit is compact.
The discharge air has pulsations necessitating pulsation dampers and air receivers.	Being a positive a displacement machine, it has some pulsations.	There is no significant pulsations at all.
Compressor is noisy	Compressor is noisy	Compressor is less noisy (<90 dBA)
High maintenance cost since piston rings, guide rings, valves, etc., are proven to failure and need periodic replacement.	Low maintenance cost except the teflon used to cast the male and female rotors wears off under the heat of compression causing the complete air end to be replaced within 3-5 years maximum. Nearly trouble free. Little change in capacity of free air delivered due to wear and tear of moving parts.	Low maintenance cost since in the compressor section there are no contacting parts.

contd.

High inventory of spare parts is necessary to keep the machine in running condition.	Less spare parts are necessary in comparison with the reciprocating compressor.	Bare minimum inventory of spare parts is necessary.
Continuous operation is not possible because of frequent maintenance shutdowns.	The majority of the moving parts is in the compressor section necessitating downtime because of failure.	Continuous service-24 hr per day, 365 days a year is available with many units running in the field for years without maintenance shutdowns.
Lowest full load power consumption	About 10-12% higher full load power consumption than a reciprocating compressor.	About 3-5% higher full load power consumption than a reciprocating compressor.
	Extra power is consumed in pumping oil for injection. Total operating cost of screw compressors lower than reciprocating compressors. Manufacturers claim 1:4 ratio.	
Lowest no load power consumption	Highest no load power consumption	
	Excellent part-load characteristics	
Operators are familiar with the equipment.	Operators are not as familiar with the equipment.	Operators are not as familiar with the equipment.
Electropneumatic control system is used.	Electropneumatic control system is used.	Fully electronic microprocessor based self monitoring system is used. The system is capable of monitoring 18 functions every 2 seconds. The control system is capable of 150 separate display messages including alarms, trips, interactive direction and readout of the compressor operating data.

Note: Compressors have some moving parts which occur in varying number in each type of compressor.

Screw Compressors

Disadvantages

- Initial capital investment of screw compressor is approximately 15 per cent higher than reciprocating compressors.

- Oil in the system has a fixed life and has to be replaced after every 1000 hours of operation.

- As oil is injected directly, oil carry-over is around 3 ppm in compressed air.

- Other parts like air filters and oil separators (filters) have to be replaced after 4000 and 5000 hours of operation respectively.

6.8.3.1 Single and Multistage compressors

Theoretically adiabatic compression requires more energy while isothermal compression requires less energy. The effects of compressor cooling and interstage cooling is to shift the compression curve towards isothermal range. Hence, multistage compression is more energy efficient as shown in Table 2.

Table 2

Theoretical kW Requirement for Compression of 100 standard cfm Air at Various Pressures

Pressure (psig)	kW Requirement		
	Single stage	Two stage	Three stage
50	8.9	8.0	-
80	11.9	10.4	10.0
100	13.4	11.5	10.9
150	16.5	13.9	13.1
200	19.4	15.7	14.5

6.8.4 Recovery of Heat of Compression

Special units are now available abroad for connection to air-cooled, oil-flooded compressors which permit energy recovery all the year round. The cooling oil is caused to bypass the normal oil cooler and enter an oil to water heat exchanger in an insulated hot water reservoir, thus heating the water for domestic or process use.

6.8.5 Moisture Removal

Water is the greatest source of trouble in any compressed air system. Atmospheric air always contains a certain amount of water vapour which is admitted along with air at the intake of the compressor.

a) After-Cooler. To prevent this moisture from condensing in the distribution system, an after-cooler should be fitted immediately after the compressor. This device reduces the total moisture content of the air by 65-75 per cent before the air enters the receiver.

b) Air Dryer. A well designed after-cooler can reduce compressed air temperatures to about 15^{o}C above the ambient air temperature. To obtain air of consistently high quality, it is essential to incorporate an air dryer in the compressed air system. An existing compressed air system can be fitted with a dryer unit which will completely eliminate condensation problems and increase the lifespan and efficiency of the air distribution network. Air dryers, however, are likely to be net consumers of energy eventhough, for instance, heat recycling within the dryer or the use of recycled compression heat during regeneration, can reduce the requirement on energy to a minimum. The use of dryers and in general, the reduction of the dewpoint of compressed air should be closely related to the requirements of the plant and the equipment installed.

6.8.6 Distribution of Compressed Air

Efficient operation of compressed air network calls for the maximum recovery of stored potential energy. In other words it must have the least acceptable pressure drop across the distribution piping.

Air Distribution Mains

To reduce pressure loss, the air distribution system should consist of a ring main with branch lines from the ring to supply the air driven equipment. The main should be given a fall of not less than 1 m in 100 m in the direction of the air flow and the spacing between the drainage points should not exceed 30 metres.

Excessive pressure drop due to inadequate pipe sizing, choked filter elements, improperly sized couplings and hoses represent energy wastage as do leaking pipe joints and couplings.

Table 3 illustrates the penalty in terms of energy wastage if the pipes used are too small.

Table 3

Pressure Loss in Air Mains

Pipe normal bore (mm)	Pressure drop per 100 (bar)	Equivalent power losses (kW)
40	1.8	9.5
50	0.65	3.4
65	0.22	1.2
80	0.04	0.2
100	0.02	0.1

Excess loss of energy can be avoided by restricting the air flow velocity to 6 m/sec. Table 4 lists the maximum recommended air flow for various sizes of the pipe.

Table 4

Recommended Velocity of Air in Pipes

Nominal Pipe Size (inch)	Maximum recommended air flow in scfm for an air pressures	
	100 psig	90 psig
1/4	6	6
1/2	20	18
1	54	50
1.5	135	125
2	220	200
3	500	450
4	875	800
6	1900	1730

scfm: Standard cubic feet per minute

6.8.7 Avoiding Leaks

Air leaks frequently occur at air receiver relief valves, pipes and hose joints, shut-off valves, quick release couplings, tools and equipment. The cumulative effect of all these leakages will sometime account for a major portion of the total compressed air handled.

Table 5 indicates the quantity of leakage with respect to the size of the opening.

Table 5

Wastage Through Leakage in Compressed Air Lines at 100 psig Pressure

Size of opening (inch)	Air leakage (scfm)	Power required to compress air being wasted (kW)
1/32	1	0.2
1/16	4	0.8
1/8	17	3.0
1/4	70	12.0
3/8	150	25.0
1/2	270	45.0

Note: Gas flow at standard condition (scfm)
Pneumatic equipment is generally rated in terms of gas volumes at standard conditions, most commonly 14.7 psia and 60^{o}F.

$$\text{Gas flow at standard condition, cfm} = \left(\frac{P}{14.7}\right)\left(\frac{520}{t+460}\right)$$

where, cfm represents the actual gas flow
P is the absolute pressure in psia
t is the gas temperature in ^{o}F

In most cases leaks are due to poor maintenance rather than improper installation and if the resultant power wastage is fully appreciated, it would be seen that any expenditure on plugging leaks could be easily recovered in energy savings.

6.8.8 Using Lower Air Pressures

This presupposes that there is good housekeeping along the lines and therefore no leaks. Where ancillary pneumatic equipment is fitted, savings in consumption and thus energy can often be obtained by checking to ensure that equipment is correctly installed in accordance with recommended practice. Generally there will also be energy savings where equipment can be operated at lower pressure, and more so when the supply arrangements are such that the actual maximum pressure output of the compressor can be reduced.

A compressor should not be operated above its recommended operating pressure as this not only wastes energy but can also lead to excessive wear with further energy wastage.

Considerable compressed air savings and thus energy can be directly made by fitting a standard type of pressure regulator to keep the supply pressure to the equipment to the minimum value necessary.

Section 9: Insulation

6.9.1 Introduction

Thermal insulation is a direct measure of saving energy by minimizing the invisible heat (transfer) loss from a hot system into a cold environment or from a hot environment into a cold system.

The extent of energy lost from a hot surface to the environment because of temperature difference is given in Table 1.

Table 1

Approximate Loss of Heat from Hot Surface

Difference in Temperature T (^{o}C)	Heat Loss ($kcal/m^2$-hr)
40	600
100	1410
150	2170
225	5430

Source: Supplied by Lloyds Insulation India Private Limited

These heat losses can be brought down to a minimum (between 90-200 $kcal/m^2$-hr) by providing proper insulating materials which are readily available and are easy to install without interrupting an operation or process.

Continuously rising energy costs or increasing costs of heat losses have upset the economics of insulation in industries.

The situation calls for udgrading the existing thermal insulation in the existing plants to reduce the energy losses taking into account the economic thickness of insulation.

6.9.2 Major Energy Losses - Causes and Remedies

Bare Pipe Flanges

In Indian industries, it is a general practice to finish the lagging at a point 80 or 100 mm from pipe flanges because:

- it is easier to work on the flange
- leaks, if any cannot go undetected

These unlagged flanges are a source of considerable heat loss as indicated in Fig.1. Some suggestions to prevent heat losses through bare flanges are given below.

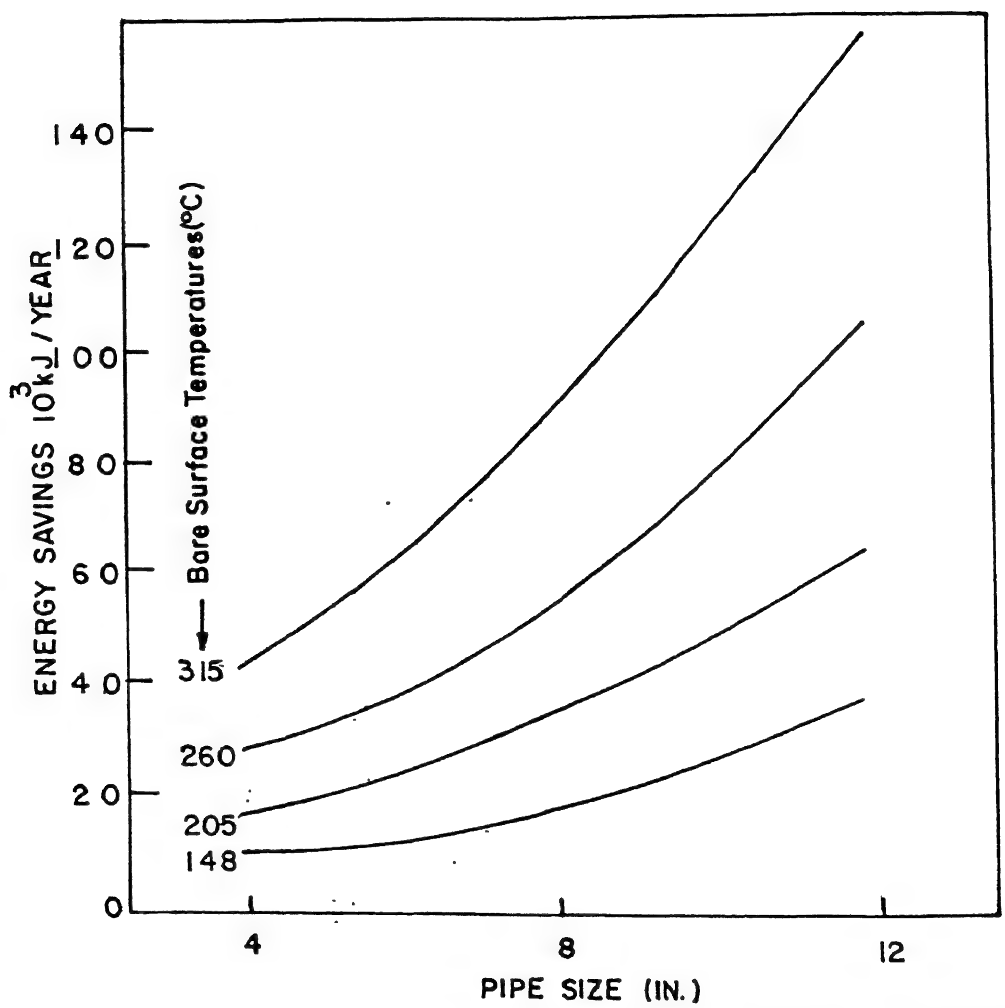

Fig.1: Estimated energy savings by insulation of flanges

- Use of moulded box lagging with a small drain pipe insertion thus facitilating easy removal of insulation with early warning of leakage if any. This system of lagging is shown in Figure 2.

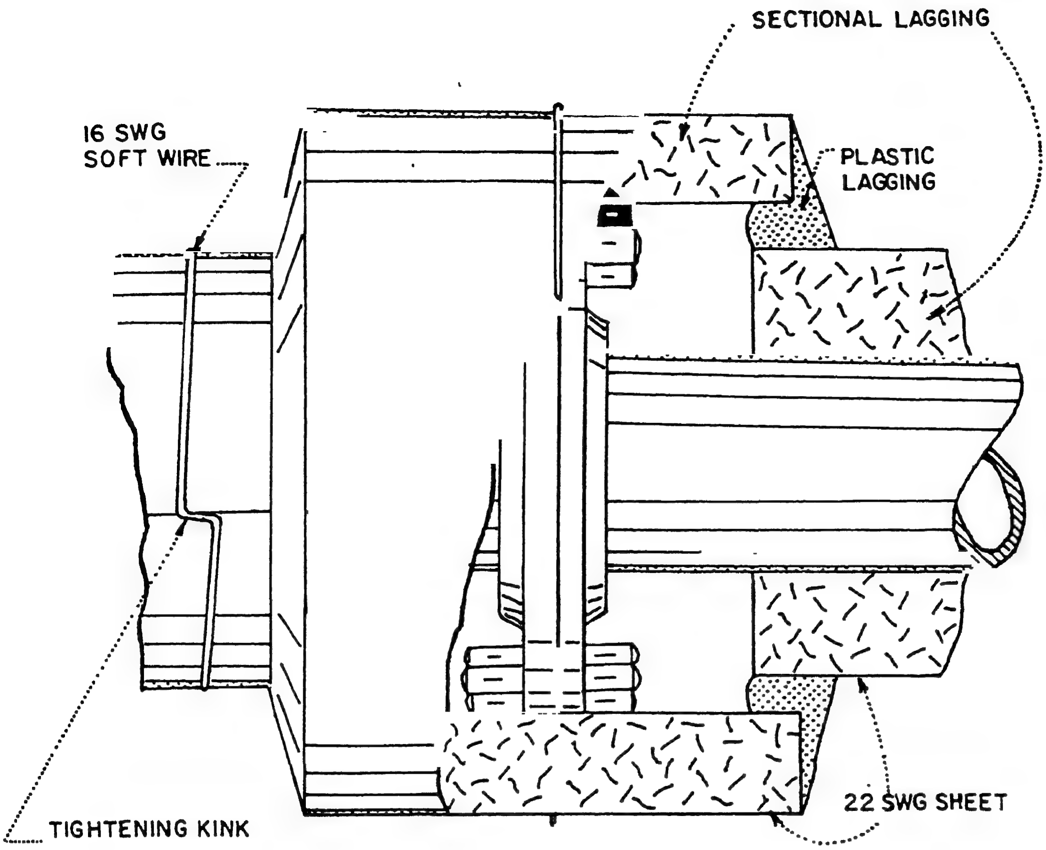

Fig.2: Sectional moulded lagging on pipe flange protected by sheet steel

- Use of insulating boxes that are made in two halves.

- A coating of aluminium paint on the surface if process temperature is low. This practice is also very effective and can reduce heat losses by 12 to 14 per cent.

Bare Valves

This situation is exactly similar to flanges as far as causes and remedies are concerned. The only difference is while comparing the heat losses in both cases. It is interesting to note that an uninsulated valve can be regarded as losing the same amount of heat as one metre of the same size uninsulated pipe and an uninsulated flange half of this.

Hot Pipes at Low Temperature

Generally pipes at low temperature are left uninsulated as heat loss through them is considered negligible. Examples of such situations are, small diameter pipes, feeding radiators or warm air units.

This perception is totally incorrect and can be clarified with the help of the following example:

Insulating a length of bare 50-mm pipe operating at 100^{o}C, supplied by a heating system operating during summer months using fuel oil can have a payback period of about six months. This illustrates clearly the need to insulate all the areas ignored up to now.

6.9.3 Insulation Materials

6.9.3.1. Important Properties

Each insulation application has a unique set of requirements as it relates to the important insulation properties. However, certain properties emerge as being the most useful for comparing different products and evaluating their fitness for a particular application.

Table 2 lists the insulation types and their properties.

Temperature Use Range

Since all products have a point at which they become thermally unstable, the upper temperature limit of an insulation is usually critical. Low-end temperature limits are usually not specified unless the product becomes too brittle or stiff and as such, unusable at low temperatures.

Thermal Conductivity,K

This property is very important in evaluating insulation since it is the basic measure of thermal efficiency. This property relates only to homogeneous materials and has nothing to do with the surface of the material. Obviously, the lower the K value, the more efficient the insulation. Since the K value changes with temperature, it is important that the insulation mean temperature be used rather than the operating temperature.

Compressive Strength

This property is important for application where the insulation will see a physical load. It may be a full time load, such as in burried lines or insulation support saddles, or it may be incidental loading from foot traffic. When comparing products it is important to identify the per cent compression at which the compressive strength is reported. Five to ten per cent compression is most common. All insulation products should be compared at the same compression level.

Table 2

Industrial Insulation Types and Properties

Insulation Type and Form	Temperature Range °C	Thermal Conductivity (kcal/m^2 hr. °C) 25°	95°	260°	Compressive Strength at % Deformation (kg/cm^2)	Fire Hazard Classification and Flame Spread/ Smoke Developed	Cell Structure (Permeability and Moisture Absorption)
Calcium silicate blocks, shapes, and pipe covering (P.C)	820	0.0458	0.05	0.06	7.03-17.6 at 5%	Noncombustible	Open cell
Glass fibre blankets	650	0.03-0.038	0.04-0.06	0.05-0.09	0.001-0.25 at 10%	Noncombustible to 25/50	Open cell
Glass fibre boards	540	0.03	0.03	0.06-0.07			
Glass fibre pipe coverings	460	0.03	0.04	0.08			
Mineral fibre blocks and P.C	1040	0.03-0.04	0.03-0.05	0.06-0.1	0.07-1.27 at 10%	Noncombustible to 25/50	Open cell
Cellular glass blocks and P.C	-270-480	0.05	0.06	0.02-0.09	7.0 at 5%	Noncombustible	Closed cell
Expanded perlite blocks, shapes, P.C	to 820	-	-	0.08	6.3 at 5%	Noncombustible	Open cell
Urethane foam blocks and P.C	-270 to 110	0.02	-	-	1.12-5.3 at 10%	25-75 to 140-400	95% closed cell
Isocyanurate foam blocks and P.C	to 180	0.02	-	-	1.2-1.75 at 10 %	25-55 to 100	93% closed cell
Phenolic foam P.C	-40 to 120	0.03	-	-	0.91-1.5 at 10%	25/50	Open cell
Elastomeric closed cell sheets and P.C	-40 to 110	0.03	-	-	2.8 at 10%	25-75 to 115-490	Closed cell
MIN-K blocks and blankets	980	0.02	0.03	0.03	7.0 to 13.35 at 8%	Noncombustible	Open cell
Ceramic fibre blankets	2580	-	-	0.05-0.07	0.35 at 10%	Noncombustible	Open cell

Source: Turner, Wayne, C., Ed., Energy Management Handbook, John Wiley and Sons, New York (1982)

Fire Hazard Classification

Insulation materials are connected with fire in two ways: fire/hazard and fire protection. Fire protection refers to the ability of a product to withstand fire exposure long enough to protect the column, pipe, or vessel it is covering whereas fire hazards relates to the product's contribution to a fire by either flame spread or smoke development.

Cell Structure

The internal cell structure of an insulation is a primary factor in determining the amount of moisture the product will absorb as well as the ease with which vapours will pass through the material. Closed cell structures tend to resist both actions, but the thickness of the cell walls and the base material will also influence the long-term performance of a closed cell product. In simple design conditions such as chilled water lines in a reasonable ambient, closed cell products can be used alone. However, at colder operating temperatures, an additional vapour barrier is suggested for proper performance.

Available Form

An insulation material comes in different shapes and configurations to suit specific applications. Flexible blankets, rigid boards and blocks, pipe insulation half-sections, and the full-round pipe sections are the most common forms.

Other Properties

For certain applications, certain other properties of insulating materials are important. The pH of a material is occasionally important if a potential for a chemical reaction exist. The specific heat of insulating materials is used together with density in calculating the amount of heat stored in the insulation system, primarily of concern in transient heat-up or cooldown cycles.

6.9.3.2 Material Description

Calcium silicate

These products are formed from a mixture of lime and silica and various reinforcing fibres. The calcium silicate products are known for exceptional mechanical

strength and durability in both intermediate and high-temperature applications where physical abuse is a problem. In addition, their thermal performance is superior to other products at high operating temperatures.

Glass Fibre

These are silica based insulations supplied in more forms, sizes and temperature limits than are other industrial insulations. The binder system employed include low-temperature organic binders, high-temperature organic binders and needled mats with no binder at all. The resulting products include flexible blankets, semi-rigid boards, and preformed one-piece pipe covering for a very wide range of applications from cryogenic to high temperatures. In general the fibre glass products are not considered for load bearing applications.

Mineral Fibre/Rockwool

Fibres of these insulation products are manufactured from molten rock or slag. Generally binders used are similar to those used in fibre glass except at very high temperatures where inorganic clay-type binders are used. Mineral wool fibres can be used at higher temperatures as they are highly heat resistant. However, use of these is not advisable in applications where long-term vibration or physical abuse is a problem as they have very short fibre length and very high percentage of unfiberized material.

Cellular Glass

This product is composed of millions of completely sealed glass cells, resulting in a rigid insulation that is totally inorganic. This provides trouble free service where moisture is a problem as in cryogenics or burried applications. Cellular glass is load bearing, but it is also somewhat brittle, making installation more difficult and causing problems in vibrating or flexing applications. Although it gives some problem at high temperatures and has higher value of thermal conductivity as compared to other materials, but it has certain unique features that make it the best product for certain applications.

Plastic Foams

There are three foam insulation materials which are used in industrial applications, primarily for cold service. They are all produced by foaming various plastic resins.

Polyurethane Foams

It is rigid and offers the lowest thermal conductivity, thus allowing the use of less insulation thickness, which is of particular importance in very cold service. Sealing in these products is necessary to resist the migration of air and water vapour back into the foam.

Phenolic Foam

They are also rigid but their K value is high. Their maximum temperature limits are so restrictive that the products are primarily limited to plumbing and refrigeration applications.

Refractories

(a) Ceramic Fibre. These alumina - silica products are available in two basic forms, needled and organic-bonded. The former contains no binder and retains its strength and flexibility even at very high temperatures. The organically bonded felts utilize various resins which provide good cold strength. The bulk ceramic fibers are also used in vacuum forming operations where different parts are moulded to specific shapes.

(b) Insulating Firebrick. These products are formed from high purity refractory clays, with alumina added to the higher temperature grades. Insulating firebricks are much lighter and therefore store less heat than the dense refractories and are much superior in terms of thermal efficiency.

6.9.4 Insulation Selection

6.9.4.1 Application Requirement

Each industrial application has some insulation specific requirements that are used to weigh the importance of the various material properties. There are three items that must always be considered to select the optimum insulation for a particular service. They are operating temperature, location or ambient environment and the form in which they are required.

6.9.4.2 Operating Temperature

- Cryogenic (-270^{o} to $-101^{o}C$). Cryogenic service conditions are very critical and require a well designed insulation system. if the process temperature is very low, the following factors are considered before selecting an effective and efficient insulation system.

  . Insulation should be adequately sealed and vapour resistant. Otherwise moisture will enter the system and expand after condensation thus leading to destruction of insulation.

  . Thermal resistance of insulation should be very high for the low temperature application. In such cases, vacuum insulation systems are generally used.

- The insulation should not be too brittle. Some plastic foams are suitable for such services.

Closed cell foam glass (cellular glass) is quiet suitable for low temperature applications in all areas except those requiring high thermal efficiency. Since it is not evacuated and has solid structure, the thermal conductivity of cellular glass is relatively high.

- Low Temperatures (-101^{o} to $100^{o}C$). This temperature range includes plumbing, HVAC and refrigeration systems used in all industries from residential to aerospace. There are many products available in this range and the cost of the installed system is a deciding factor. Products typically used are glass fibre, plastic foams, phenolic foams, elastomeric materials and cellular glass. In below-ambient temperature conditions, a vapour barrier is still required.

- Intermediate Temperatures (100^{o} - $540^{o}C$). The great majority of steam and hot process applications fall within this operating range. Refineries, power plants, chemical plants, and manufacturing operations require insulation for piping and equipment at these temperatures. The products generally used are calcium silicate, glass fibre, mineral wool and expanded perlite. The significant factors to be considered for insulation selection are:

  . Change in thermal conductivity of the material over the range of mean temperatures, especially for light density products.

- High Temperature Range (540^{o} - 870^{o}C). Superheated steam, boiler exhaust ducting, and some temprature operations deal with temperatures at this level. Calcium silicate, mineral wool, and expanded perlite products are commonly used together with the lower - limit ceramic fibres. Thermal instability is usually the limiting factor.

- Refractory Range (870^{o} - 1980^{o}C). Furnaces and kilns in steel mills, heat treating and forging shops, as well as in brick and ceramic tile operations, operate in this range. Many types of ceramic fibres are used, with alumina-silica fibers being the most common. Again thermal instability is the controlling factor in determining the upper temperature limits of many products employed.

6.9.4.3 Location

The second item to be considered in insulation selection is the location of the system. Location includes many factors that are critical to choosing the most cost-effective product for the life of the application.

Surrounding Environment. For an insulation to remain effective, it must maintain its thickness and thermal conductivity over time. Therefore, the system must either be protected from or able to withstand the rigors of the environment. Some surrounding environment conditions and use of different insulations for specific conditions are listed below.

Surrounding Environment	Factors to be considered	Recommendations for Suitable Insulation
- Outdoor systems	- Entering of water into the insulation	- water vapour barrier should be provided in insulation
- Indoor systems	- Moisture - Chemical fumes, depending upon the process of the system	- Barrier material should be sealed from moisture - Insulation should have chemical resistance
- Direct burial systems	- Soil Loading - Corrosion - Moisture	- Barrier material to be sealed from ground water and and be made resistant to corrosion

Contd.

Contd.

Surrounding Environment	Factors to be Considered	Recommendations for Suitable Insulation
		- Insulation should have high compressive strength
- Application where vibrations are severe, i.e., gas turbine exhaust stack	- Fatigue resistance	- Avoid use of fibrous material especially at elevated temperatures because at high temperatures, fibres lose much of their compressive strength & resiliency
- Fire prone area	- Insulation should not carry fire to another area and should help in protecting the piping and equipment	- Products having water of hydration should be used. Calcium silicate is the best material.
- Transport of volatile fluid through the piping system	- Due to absorption of volatile fluids, insulation leaks around flanges or valves, which may create fire hazards if flash point of fluid is below the operating temperature	- Closed cell material such as cellular glass should be used

- Resistance to physical abuse. Physical abuse differs from physical loading in that loading is planned and designed for, whereas abuse is not. The abuse may lead to:

  . Puncturing of non-metal jackets

  . Deforming of jacket may lead to compression of insulating material and hence, may lead to much poorer insulation due to reduction in thickness

  . Water may enter the system as a result of deformation at the jacketing overlap, thus degrading the insulation and reducing the thermal efficiency.

In an effort to deal with the physical abuse problem, all horizontal piping should be insulated with rigid material. Calcium silicate, cellular glass, and expanded perlite products fit the rigid category.

6.9.5 Cost Factor

For most situations, taking into consideration the application requirements, we have a choice of selecting a particular insulation among the various materials. In these cases, several cost factors should be considered before making a final choice. These cost factors are discussed one by one.

Initial cost. Among the various materials giving similar thermal performance, it may be of substantial benefit to utilise a more costly material that can be installed more efficiently with reduced labour costs. The lowest-cost material does not necessarily become the lowest-cost installed material, so all acceptable alternatives should be evaluated.

Maintenance cost. To keep the performance and appearance at acceptable levels, all insulation systems must be maintained properly. It may be possible that a less costly system may well require greater maintenance as compared to some other costlier systems. So it is imperative that both aspects, i.e. cost of initial construction and cost of ongoing maintenance be viewed simultaneously before making a final decision.

Lost heat cost. If a common thickness is specified for all products, there can be a substantial difference in heat loss or gain between the systems. In such a case, the more efficient product should receive financial credit for transferring less heat, and this should be considered in the overall cost calulations.

6.9.6 Evaluation of Critical Thickness of Insulation

6.9.6.1 Economic Thickness of Insulation

That thickness which, for a given set of conditions, results in the lowest overall cost of insulation and heat loss combined over a given period of time, is called the economic thickness of insulation. The principles behind the economic thickness of insulation can be understood from Fig.3.

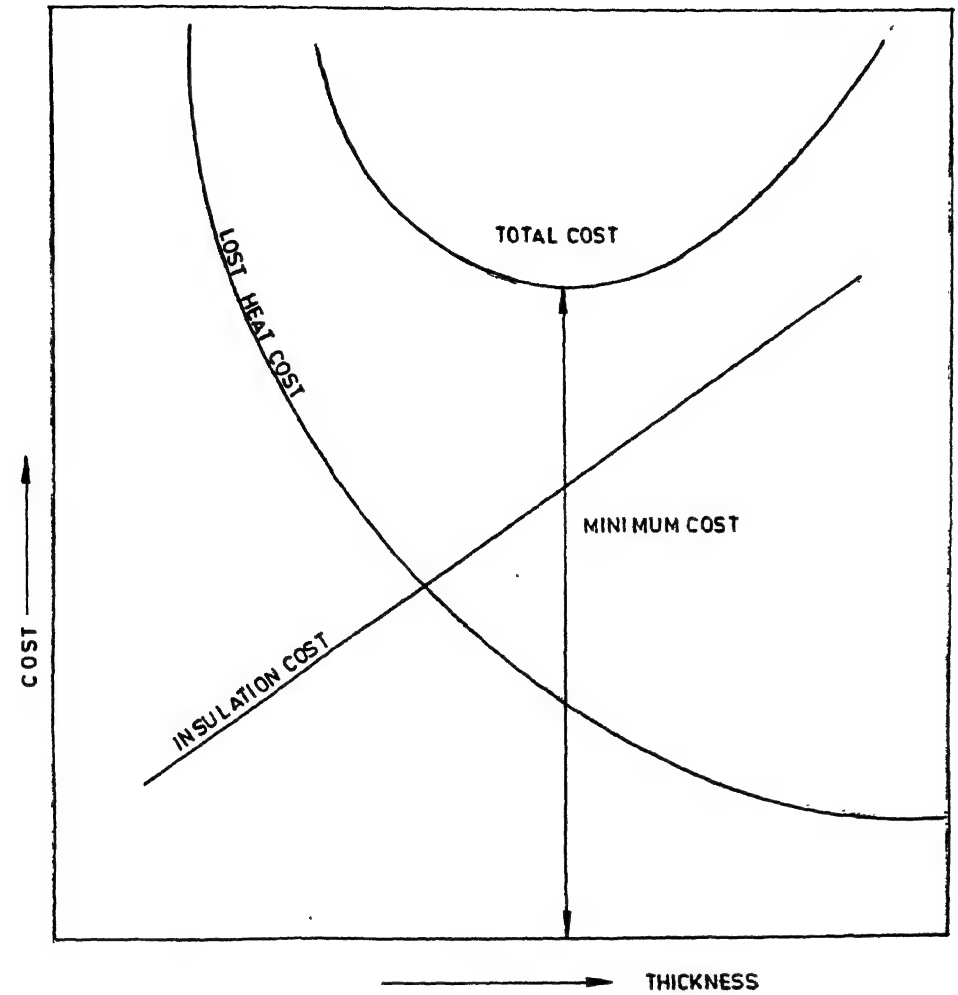

Fig.3: Economic thickness of insulation concept

6.9.6.2 Calculation Steps

The general procedure for calculating the optimum economic thicknesss of insulation is to assess the cost of heat lost plus the cost of insulation at different thicknesses, and then selecting that thickness for which the total cost is minimum. Economic thickness of insulation may be determined by considering discounted cash flow, depreciation costs, maintenance costs, future fuel prices, etc. to get more accurate results.

For calculating the economic thickness of insulation some information is needed for optimum results. These cover:

- cost of fuel
- boiler/furnace efficiency
- total number of hours of operation of the system per year

- number of years

- installed cost of insulation

- heat loss per metre run.

The cost of fuel, boiler/furnace efficiency, hours of operation per year, evaluation period and installed cost of insulation can be obtained without any calculation and the heat loss per metre-run can be obtained from a supplier along with the cost of insulation or can be calculated using heat transfer calculations.

Before deciding about the economic thickness of insulation one must know :-

- cost of useful heat

- cost factor

- cost of heat lost

Cost of useful heat. It is based upon the cost of fuel and boiler/furnace efficiency. For the total cost of useful heat some other factors such as capital cost, maintenance cost, general running cost are also to be considered. Thus to get cost of useful heat one has to take the gross fuel cost and divide it by the efficiency.

Cost factor. The cost factor is the value of unit heat loss over the evaluation period in monetary terms

The two factors invovled in finding out the total value of heat loss are:

- Energy loss per unit length of pipe (W/m^2)

- Evaluation period (seconds)

Cost of heat lost. It is simply the product of the cost factor and the heat lost from the pipe.

After knowing the cost of heat lost for each thickness, we have to add the cost of installation for each thickness. Then the thickness with the minimum cost is taken as economic thickness of insulation.

Projects

1. Evaluate the effectiveness of various types of insulation in your plant/workshop, and estimate energy savings where improvements are needed.

2. Estimate investment and payback periods for insulation addition, repair or upgradation.

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Section 10: Electrical Energy Conservation

6.10.1 Introduction

The availability of an adequate amount of good quality electricity energy is essential for the industrial development of the country. Though there has been a phenomenal increase in the installed generation capacity during the past 40 years, the demand for power has outstripped availability causing widespread shortages for power in different parts of the country.

The major brunt of this power supply shortage has been, and will be faced by the industrial sector which accounts for about 47 per cent of electricity consumed in the country. Besides having to live with poor quality and unpredictable supply of power, industries also have to cope with ever increasing energy prices. Recent events and future prospects for the demand and supply of electricity have underscored the necessity of giving conservation greater weightage.

This requires efforts in two directions - maximizing energy efficiency in existing industrial units, and adopting the most energy efficient technologies for future expansion and growth. The majority of industrial production today is based on processes, technologies and equipment designed and built when energy was cheap and readily available. As a result of this, there is a large potential for energy conservation which has been estimated to be in the range of 20-30 per cent of the energy being used presently. These savings can be realized through energy conservation measures ranging from improved housekeeping practices to minor modifications in existing equipment to major equipment/process modifications.

Conservation practices in industry, however, will depend very heavily on the cost and availability of fuel/power, and the motivation for implementing conservation schemes is influenced by a number of forces which relate to technical, economic and financial factors. In addition, institutional regulations and constraints are very often the dominant factors.

6.10.2 Electrical Energy Use

Electricity in industry is mainly used for lighting, providing motive power, heating and electrolysis. Of these, electricity used for motive power alone accounts for about 72 per cent of the total electricity consumption of the industrial sector (as estimated in a recent study conducted by TERI).

Electrical energy consumption can be reduced by elimination or attenuation. Energy conservation schemes normally employ the latter method to reduce electricity consumption.

Electrical energy management can be effected by taking a variety of steps depending upon their suitability for a particular application.

(i) Use proper/optimal controls - use timers, electronic/microprocessor based controls, variable speed drives for motors, etc. to provide better control over the process, which in turn could be used to optimize the functioning of equipment thereby reducing energy consumption;

(ii) Optimize capacity - As far as possible, it is better to optimize capacity since excess capacity would result in underutilization which leads to inefficiencies;

(iii) Reduce loads - As far as possible avoid loads which are non-essential to the production process;

(iv) Use more efficient processes - Technological changes have made possible the use of more efficient processes which are not only more effective, but also reduce energy consumption. For example, use of infrared heating instead of resistive heating, where applicable;

(v) Use more efficient equipment - Energy consumption can be reduced by using more efficient equipment, such as energy-efficient motors, efficient lamps, etc.;

(vi) Employ special techniques - Use of power factor correction capacitors, resizing the distribution system, etc. would lead to further reductions in energy consumption;

(vii) Effectively contain energy and reduce losses - Installing heat recovery systems and better insulation are examples whereby energy could be contained and energy consumption reduced;

(viii) Cascade energy use - Energy use efficiency can be further improved by cascading energy use. For example, cogeneration of process heat/steam and power.

It is difficult to be exhaustive in reviewing various electrical energy conservation schemes because of the enormous diversity of industrial processes, technologies

and equipment, each having unique features and thus calling for unique energy conservation measures. This section deals with some techniques for identifying the potential for savings and for reducing electricity consumption in specific equipment like motors, lighting systems, heating, electrolysis and load management.

6.10.3 Electrical Energy Analysis

An electrical energy conservation programme requires:

- a systematic approach to electrical energy analysis and

- an investigation of all related systems which contribute to the consumption of electrical energy.

A systematic and detailed analysis of historical energy use data is essential to determine the energy use pattern. This analysis should be carried out at both the plant level as well as for specific equipment/system.

A systematic energy analysis requires a detailed energy balance on each process, activity or facility, for a critical analysis of fuel use and identification of the potential for conservation. Such an analysis would help establish a benchmark or baseline of energy-use and energy-use pattern. Based on this reference datum, it could be determined where energy is being lost, and how much is being lost.

Effective measurement and monitoring procedures would be essential for such an evaluation. Energy meters would have to be installed not only at the mains but also at distribution boards within the plant and at specific equipment/system which are known to be major energy consuming centres. The composite system load may be broken down to subsystems such as lighting load, motor load, heating load and electrolytic load to characterize electricity use in these systems.

The analysis should also include computation of the connected load, the maximum demand, the load factor - defined as the ratio of the average demand to the maximum demand, and the power factor. The variations in these during different periods of time and for different cycles of operation should also be accounted for.

6.10.4 Electrical Load Management

Electrical load management is the process of scheduling load usage so as to reduce electricity use during peak load periods. Load management generally means increasing the electricity consumption during off-peak periods. The

goal of a load management programme is to maintain, as nearly as possible, a constant level of load, thereby allowing the system load factor to approach 100 per cent.

The major benefit from load management is a reduction in the peak demand which would reduce the demand charges. It would also release a part of the system capacity for additional loads (in case of any expansion) to be placed on the system without the need for an additional transformer. Provided of course, that the additional load does not exceed the difference between the reduced peak load and the capacity of the existing transformer.

To conduct a load management programme, it is essential that the system load curve for the plant be defined to ascertain the peak load. Peaks may occur either due to system faults or due to improper management. Only by monitoring and analysing the load curve on a regular basis can the cause for peaks be ascertained. On the basis of this analysis, loads can be rescheduled to reduce the peaks. This would, depend on operational constraints and whether or not loads can be rescheduled.

Demand control, to limit peak power, can be effected by three basic methods:

i) Timed control
ii) Manual control
iii) Centralised control

In timed control, loads are switched off or on according to a continuous cycle based on an estimate of peak load times. In this control there is no input concerning the rate of energy consumption by the load. Therefore, the effectiveness of timed control depends on a consistent cyclic energy consumption pattern.

In the manual control method an operator monitors a demand meter at all demand intervals that occur during peak load periods and determines when to turn off or turn on loads so as to prevent the demand from exceeding a pre-determined limit. Since this method is dependent on human decision making ability, its accuracy decreases with increasing number of loads to be controlled.

Systems having many loads are best controlled by instrumentation such as hardwired controllers and computers. Centralised control devices monitor the system energy consumption and/or the demand and decide when loads should be switched off or on. The process of switching loads off or on is referred to as load shedding or load restoring. The total possible load shedding potential (LSP) for a system is given by:

$$LSP = \frac{1}{\Delta t} \sum_{i=1}^{n} (L_i \times t_{off})$$

where, Δt is the demand interval in minutes, L_i is the load (kW) under consideration for shedding, and t_{off} is the allowable off-time in minutes during the demand interval of the L_i load. The LSP represents the maximum possible reduction in demand for the system through load shedding.

Loads which are shed are restored after the permissible off-time. The restored loads may be recoverable or non-recoverable. Recoverable loads are those in which, the amount of energy saved during the shedding time of the load would be consumed after the load is restored to regain the normal operating level. For example, a pump which has been switched off to reduce consumption during peak load periods would consume the required amount of energy when it is switched on later during non-peak hours. In this case no energy is conserved but since the energy consumption has been deferred from a peak load period to an off-peak load period, the system load factor improves and demand charges, where applicable, are reduced. In case of non-recoverable loads not only is the demand reduced but energy is also conserved. For example, ventilation and exhaust fans would not consume any extra energy after they are restored to regain the normal operating level.

In determining loads which could be shed, it is important to study loads in terms of any harmful effects that could result due to load-shedding operations. For example, large motors may not be good candidates for load-shedding because of the large inrush starting currents and start/stop stresses (however, where possible, their operating time could be deferred). Production loads which cannot be turned off at will are termed as base loads.

Centralized demand control for load management requires adequate instrumentation for data acquisition so that energy consumption can be monitored. Demand monitors are commercially available which can be programmed for a pre-determined demand. As soon as the load increases beyond the fixed demand, loads are shed according to a pre-programmed priority. Loads are later restored as the demand reduces. Demand monitors normally operate based on a comparison of the instantaneous rate of energy consumption to a preset ideal rate.

Load management would have far reaching benefits since a reduction in the peak load would be reflected not only in reduced demand charges but also in reduced line losses and consequently, improved voltage regulation and improved system efficiency.

6.10.5 Power Factor Correction

Power factor is defined as the ratio of real power (kW) to the apparent power (kVA) and is the cosine of the angle by which the current lags (or leads) the voltage. In case of inductive loads, the current lags the voltage and the power factor is 'lagging'; whereas in the case of capacitive loads, the current leads the voltage and the power factor is 'leading'.

Most industrial electric loads like motors, welding sets, light sources using ballasts, etc. are inductive in nature and the overall power factor of the plant is low and lagging. Poor power factor results in increased reactive current resulting in increased total current drawn which is the vector sum of the reactive and working components of the current as given by

$$I_T = \sqrt{(I_W)^2 + (I_m)^2}$$

where I_T is the total current, I_W is the working component of the total current and I_m is the magnetizing component. With an increase in the total current drawn, the I^2R losses in the line increase, which also results in greater voltage drop across the line leading to poor voltage regulation. Poor power factor also results in increased reactive power which leads to increased kVA demand which is given by:

$$kVA = \sqrt{(kW)^2 + (kVAR)^2}$$

where kVA is the apparent power, kW is the real component and kVAR the reactive component of power.

Poor power factor can be corrected by either using shunt capacitors or by using sychronous motors which can be operated at leading power factor to compensate for loads with lagging power factor. Sychronous motors are very expensive and are used only in a few industries; therefore the use of shunt capacitors is most suitable for power factor correction.

Installation of capacitors results in leading current and thus compensate for the lagging current drawn by the load. To determine the rating of a capacitor required for a particular load, it is necessary to determine the reactive power of the load.

The capacitor rating required to improve the power factor from an existing value to a desired value can be computed using the relation:

$$CkVAR = kW \times (\tan\Theta_1 - \tan\Theta_2)$$

where CkVAR = capacitor kVAR required

kW = load in kW

θ_1 = $\cos^{-1}$ (existing power factor)

θ_2 = $\cos^{-1}$ (desired power factor)

Alternatively, power factor correction tables may be used to determine the rating of capacitors required to improve the power factor from an existing value to a desired value. Table 1 gives the kW multipliers for determining the capacitor kilovars required for power factor improvement.

Capacitors may be installed at a substation, at distribution boards, at individual loads or provided at all these locations to improve power factor at different stages and avoid the high cost of installing low-rating capacitors. Ideally, capacitors should be connected as near to the load as possible to get the maximum benefit, since improvements due to capacitors are reflected backwards from the point of installation to the generators. Therefore by providing capacitors only at the substation, the industry would avoid the penalty for poor power factor but would lose out on other benefits such as reduced line losses, reduced loading of cables, improved voltage regulation and increased system efficiency. However, small- and medium-sized industries which do not pay a tariff based on the kVA demand, may not find it economical to install capacitors at individual load points.

In installing capacitors, however, care should be taken that the capacitor rating is properly selected. Over-compensation is equally harmful and may also give rise to excessive voltage build-up when the motor is switched-off. In case of capacitor compensation for motors, it should be ensured that the capacitor current is not greater than the no-load current of the motor or, the capacitor kVAR is not greater than about 90 per cent of the no-load kVAR of the motor. Similarly, when connecting capacitors at distribution panels it should be ensured that loads are not switched-off with all capacitors connected in circuit.

In addition to the savings that are evident, there are other savings which are more difficult to quantify. For example, improved voltage regulation results in better operation of other equipment leading to an overall increase in system efficiency. In the final analysis, however, the installation of capacitors is influenced by the tariff structure, the cost, and the monetary savings that could be achieved.

Table 1

KW Multipliers for Determining the Capacitor Kilovars Required for Power-factor Improvement

Original power factor $\cos \theta_1$	Desired improved power factor, $\cos \theta_2$																				
	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81	.....	0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82	.....	.....	0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83	.....	.....	.....	0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84	.....	.....	.....	.....	0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85	.....	.....	.....	.....	.....	0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86	.....	.....	.....	.....	.....	.....	0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87	.....	.....	.....	.....	.....	.....	.....	0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.037	0.079	0.126	0.186	0.329
0.96	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.041	0.089	0.149	0.292
0.97	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.048	0.108	0.251
0.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.060	0.203
0.99	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	0.143
																					0.000

POWER-FACTOR IMPROVEMENT

POWER-FACTOR IMPROVEMENT

EXAMPLE. Find the ckvar to improve the power factor of a 500-kw load from 0.7 to 0.95.

$$\begin{aligned} \text{ckvar} &= \text{kw} \times \text{multiplier} \\ &= 500 \times 0.691 \\ &= 345.5 \end{aligned}$$

6.10.6 Power Distribution System

Proper design of electrical distribution system is essential for smooth functioning of any industrial facility. Therefore, it is essential that a careful study of the electrical power requirements of the plant be made to ensure installation of the most suitable power system network.

There are many factors which govern the selection and design of a power distribution system. Some of the important considerations are cost, safety, flexibility, service reliability, ease of expansion, diversity, voltage regulation and short-circuit current levels. Sound engineering principles and judgement are to be applied to determine The capacity of the transformer. For example, providing larger transformer reserve capacity than required not only results in higher transformer costs but also increased cable and switch gear costs, since larger systems have lower impedance resulting in higher short-circuit currents.

The most commonly used power distribution circuits are the radial and secondary selective networks. Radial systems employ one transformer fed from a primary feeder through which a secondary bus is served. Since there is no duplication of equipment in this system, initial costs are low and this system affords a high degree of reliability. However, in the event that the primary feeder or the transformer fails, or requires maintenance, the entire area to which power is fed from that transformer has to be deenergized.

In the secondary selective circuit arrangement, the radial arrangement is modified so that secondary sub-stations can either be operated independently or a tie line, normally open, could be closed so that in the event of one of the transformers being out of service, power can be fed to different sub-stations from a single transformer Since under normal operating conditions the tie lines are open, the short-circuit currents are not increased. This system, therefore, has all the advantages of a radial system with only a marginal increase in costs. Since in this system it is possible to meet the power requirement of two load centres through a single transformer, the capacity of the transformers should be carefully selected. It is important to realize that with high transformer costs, it is not economical to provide unnecessary large reserve capacity. Therefore, a careful study of the loads should be made to seggregate essential and non-essential loads and determine the load diversity and peak before deciding on the reserve capacity to be provided. It may also be noted that no parelleling of transformers is involved in this

arrangement. Parallel operation of transformers necessitates a more complex protection system and higher capacity switching systems due to the increased short-circuit currents.

The systems mentioned above afford very high reliability at comparitively low cost. However, depending upon the load requirement, greater flexibility can be provided by installing a double bus bar system, especially in systems where captive power plants meet the power requirements of a plant for a substantial period of time. This system affords greater flexibility in the manner in which power can be supplied to various sections of the plant. Also, in the event that the sanctioned demand is lower than the requirement, both grid power and that supplied by the captive plant can be used and fed interchangeably to different load centres.

As power distribution systems are dependent on various factors which are site specific, it is not possible to provide exhaustive details of the methods to be applied in determining the most suitable system. Therefore, in this section only an attempt has been made to highlight some of the more important factors which should be considered before installing a new system or modifying an installed system. It is recommended that the services of an experienced consultant be employed for proper design of power distribution systems.

6.10.7 Lighting

Electricity consumed in industrial lighting normally varies from a small fraction to about 5 per cent of the total electricity consumption. In absolute terms, however, it might form a substantial quantity in many industries. With proper design and selection of lamps, substantial savings in electricity consumption could be achieved. Good lighting, however, is influenced by many factors which include physiological and psychological factors. Though it would be difficult to deal with all the factors which influence good lighting and visual performance, some of the important considerations which have to be borne in mind when deciding on a new lighting system or when considering a change, are dealt with in the following paragraphs.

Human vision is not equally sensitive to all parts of the visible spectrum. The peak sensitivity of the human photopic vision (used in bright illumination) occurs at the wavelength of 555 nanometre (nm). At higher and lower wavelengths the sensitivity (technically known as spectral luminous efficiency) decreases. The response for wavelength less than 380 nm and greater the 760 nm is negligibly small.

Two measures of visibility are 1) minimum perceptible contrast, and 2) visual acuity.

Minimum perceptible contrast is the minimum perceptible difference in luminance that can be perceived between a small dot and its surroundings. For low background luminance, increasing lighting levels decrease the minimum perceptible contrast. However, at high luminance levels increasing the background luminance has little benefit.

It might therefore be less expensive and more effective to redesign the task to improve its contrast than to increase illumination. For example, using white paper instead of coloured paper in an office would improve contrast thus producing less strain while reading. It is important to realize that the illumination required is determined by task contrast.

Visual acuity is the measure of the ability to perceive detail. Here again, beyond a certain limit, redesigning the task is more beneficial than increasing the illumination. Another factor which affects visual performance is veiling reflections.

Veiling reflections are a form of reflected glare where the task surface acts as a mirror, reflecting light directly into the eyes of the observer. Veiling reflections decrease task contrast, but their effect is milder than disability glare. Veiling reflections can be avoided by proper placement of light fixtures. For example, placing the light source behind or above a person seated at a desk is better than placing it in front of the person.

Selecting the most suitable lamp for an application is of the utmost importance. Now-a-days, incandescent lamps are rarely used in industries and lighting is generally provided by fluorescent lamps. Mercury vapour and high pressure sodium vapour lamps are also increasingly being used in industry.

The efficacy of a lamp is defined by the ratio of the lumen output to the lamp wattage. The efficacy of different lamp sources are given in Table 2. The colour rendering characteristics of different lamps is given in Table 3. It can be seen from these tables that high pressure sodium vapour lamps are amongst the most efficient light sources. Though its colour rendition is not as good as that of fluorescent lamps, it can be effectively used in most factory areas. It is, however, not suitable for areas where components may be colour coded (like in electronic industries) or in paint shops and certain areas in textile industries, etc.

Table 2

Efficacies of Different Types and Wattages of Lamps

Type of Lamp	Efficacy (lumens/watt)
GLS incandescent (25W to 1000W)	8 - 18
Tungsten halogen (300W to 1000W)	22 - 27
TLD fluorescent (18W, 36W, 58W)	61 - 72
TL fluorescent (20W, 40W, 65W)	55 - 65
High pressure mercury vapour (HPLN) (80W, 125W, 250W, 400W, 1000W)	40 - 57
High pressure sodium vapour (SON, SON-T) (70W, 150W, 250W, 400W)	82 - 120
Low pressure sodium vapour (SOX)	100 - 140
PL (9W, 11W)	60 - 70

Proper lighting design has to take into account various factors such as:

- Area of work place
- Type of activity to be performed
- Type of lamp best suited to provide the desired illumination
- Type of luminaire to be used
- Mounting height of lamps
- Lighting arrangement/distribution
- Switching arrangement
- Colour/reflectance of walls, ceiling and floor
- Use of daylighting
- Colour rendition required
- Average age of persons working in the area

The activity to be performed, the colour rendition required and the illumination to be provided at the task determine the light source which is most suitable. The general tendency is to provide uniform light levels at all locations which in turn would be determined by the illumination required for the most difficult task to be performed. This results in wastage of electricity. Non-uniform lighting can be the key for providing good illumination. However, it should be ensured that it does not create sharp contrasts.

TABLE 3

Light Sources and Their Characteristics

A Guide for Lamp Selection Based on General Color Rendering Properties

Type of Lamp	Efficacy (lpw)	Lamp Appearance Effect on Neutral Surfaces	Effect on "Atmos-phere"	Colors Streng-thened	Colors Grayed	Effect on Com-plexions	Remarks
Fluorescent Lamps							
Cool[a] white CW	High	White	Neutral to moderately cool	Orange, yellow, blue	Red	Pale pink	Blends with natural daylight—good color acceptance
Deluxe[a] cool white CWX	Medium	White	Neutral to moderately cool	All nearly equal	None appreci-ably	Most natural	Best overall color rendition, simula-tes natural daylight
Warm[b] White WW	High	Yellowish white	Warm	Orange, yellow	Red, green, blue	Sallow	Blends with incan-descent light—poor color acceptance
Deluxe[b] warm white WWX	Medium	Yellowish white	Warm	Red, orange, yellow, green	Blue	Ruddy	Good color rendi-tions simulates in-candescent light
Daylight	Medium-high	Bluish white	Very cool	Green, blue	Red, orange	Grayed	Usually replaceable with CW
White	High	Pale yellow-ish white	Moderately warm	Orange, yellow	Red, green blue	Pale	Usually replaceable with CW or WW
Soft white/ natural	Medium	Purplish white	Warm pinkish	Red, orange	Green, blue	Ruddy pink	Tinted source usually replaceable with CWX OR WWX
incandescent Lamps, Tungsten Halogen							
Incandescent filament.	Low	Yellowish white	Warm	Red, orange, yellow	Blue	Ruddiest	Good color rendering
High—Intensity Discharge Lamps							
Clear mercury	Medium	Greenish blue-white	Very cool, greenish	Yellow, blue, green	Red, orange	Greenish	Very poor color rendering
White mercury	Medium	Greenish white	Moderately cool, greenish	Yellow, green, blue	Red, orange	Very pale	Moderate color rendering
Deluxe white[a] mercury	Medium	Purplish white	Warm, purplish	Red, blue, yellow	Green	Ruddy	Color acceptance similar to CW fluorescent
Metal halide[a]	High	Greenish white	Moderately cool, greenish	Yellow, green, blue	Red	Grayed	Color acceptance similar to CW fluorescent
High-pressure Sodium[a]	High	Yellowish	Warm, Yellowish	Yellow green orange	Red, blue	Yellowish	Color acceptance approaches that of WW fluorescent

Source. Courtesy of General Electric Co., **Lamp Division.**

[a] Greater preference at higher levels.

[b] Greater preference at lower levels

Task lighting is one of the most effective ways of providing acceptable levels of illumination at the work place. Background lighting however, has to be provided to ensure visibility even when task lights are turned off. Task lighting provides considerable potential for electricity saving since lamps can be selectively switched off. For office areas, however, uniform lighting is more suitable.

To provide proper lighting, it is also important to select the right luminaire and mount it at the right height. The most efficient lamps would not provide proper illumination if used with a badly designed luminaire. Similarly, by mounting the fixture at a height greater than, or very much lower than that specified by lamp manufacturers would result in inadequate lighting.

Provision of proper switching arrangement is perhaps the single most effective way of reducing electricity consumption in lighting. Switching arrangement should be provided such that lamps can be selectively switched off when not required. An effective means of reducing lighting electricity consumption would be to provide separate switches for lamps along windows so that they may be switched off when there is adequate daylighting. Daylighting can be improved by providing skylights and transluscent fibre reinforced plastic (FRP) sheets on the ceiling.

All efforts at providing good lighting can be negated by inadequate maintenance of the lighting system. It is important that lamps and luminaires are cleaned at periodic intervals to ensure that fixtures provide the illumination levels they were designed for. However, over a period of time the lumen output from lamps depreciates and it is advisable to replace lamps at the end of their economic life (defined as the time by which lamp lumen output reduces to about 70-75 per cent of the design value). Group relamping programmes are most suitable to ensure uniformity of illumination from multi-lamp fixtures.

Even in existing lighting system, electricity consumption can be reduced in a number of ways. Using slim tubelights and electronic ballasts is one way of reducing electricity consumed in fluorescent lamps. A summary of measures by which lighting electricity consumption could be reduced in both new and existing systems is given below.

(i) Design lighting for the task

(ii) Provide the required illumination for visual tasks in working areas only, and appropriate lower levels in the general areas such as corridors, storage, and circulation areas.

(iii) Reduce the wattage required for each specific task by reviewing user needs and methods of providing illumination.

(iv) Consider only the amount of illumination required for the specific task, taking into account the duration, the character, and the user performance required.

(v) Group similar tasks together for optimal conservation of energy per floor.

(vi) Consider use of greater contrast between tasks and background lighting.

(vii) Select proper lighting systems.

(viii) Avoid decorative floodlighting and display lighting.

(ix) Use fixtures that give high contrast rendition at task.

(x) Reduce lighting requirements for hazards

a. Use light fixtures close to and focussed on hazard

b. Increase contrast of hazards; e.g., paint stair treads and risers white with black nosings (strips).

(xi) Keep exterior lighting to a minimum.

a. Eliminate exterior lighting except where used for identifying the building entrances and/or for security.

b. Consider intruder-activated devices rather than photo or time-controlled illuminated security luminaires.

c. Coordinate street lighting with security lighting and eliminate duplication.

d. Use high-efficiency light sources (high-pressure sodium or high-intensity-discharge lamps).

e. Use efficient luminaires (prismatically controlled lens, rather than general diffusion or decorative geometric forms).

f. Use photocells for turning on exterior lights, and timers for turning them off.

(xii) Select the most efficient luminaires.

(xiii) Consider the use of polarized lenses to improve the quality of lighting at tasks.

(xiv) Consider the use of high-frequency electronic ballast to reduce wattage per lumen output. (Additional bene-fits are reduced ballast heat loss and longer lamp life).

(xv) Select the most efficient light sources.

(xvi) Consider the use of light colours for walls, floors, and ceilings to increase reflectance (but avoid specular reflections)

(xvii) Lower ceiling or mounting height of luminaires to increase the level of illumination with less wattage.

(xviii) Select furniture and interior decorations that do not have glassy surfaces or give specular reflections

(xix) Use high-reflectance finishes on room surfaces (particularly vertical surfaces).

(xx) Lay out the luminaires for visual performance rather than uniform space geometry.

(xxi) Within the limits of the luminaire supporting system, locate the luminaire as close to or, directly over the task, as possible without creating excessive reflections.

(xxii) Avoid locating luminaires directly in front of the visual task.

(xxiii) In multiple-task areas luminaires should be located between the desks so that the main lighting components originate from either or both sides of the desk.

(xxiv) Design switch circuits to permit turning off unused or unnecessary lights.

(xxv) Provide timers to automatically turn off lights in remote or seldom used areas.

(xxvi) Utilize daylight

The key element in a lighting management programme appears to be the perception of the workers whose working conditions the management is trying to improve.

This perception can occur by repainting equipment, decorating walls, improving the distribution of lighting,

and so on. In essence, management's show of concern for the employees appears to be the determining factor.

Removing light fixtures to save money can often be interpreted as taking something away from the workers and can decrease productivity simply by affecting workers' morale. In fact, the problem of optimizing lighting to save energy is usually quite closely tied with the problem of relationship between the workers and the management.

A successful programme for improving energy efficiency in lighting must pay considerable attention to the perception by the workers of the management, of the energy efficiency programmes and its recommended changes.

6.10.8 Motors

Electric motors in industry constitute the single largest component of the electrical load and account for about 72 per cent of the total electrical energy consumed by the industrial sector. Both AC - squirrel cage induction, slipring induction and synchronous -, and DC motors find application in industry. Squirrel cage induction motors are the most widely used because of their low cost, reliability of operation and ruggedness. In a recent study conducted by TERI on industrial electric motors, it has been estimated that squirrel cage motors form almost the entire load below the size of 20 hp and in fact, account for nearly 70 per cent of the entire motor load. Slipring, synchronous and DC motors are normally used in higher ratings and for specific applications. It has also been estimated that in industries without electrolytic loads, motor electricity consumption accounts for 80 per cent of the total consumption. In view of these facts, the importance of energy conservation in motors cannot be understated.

6.10.8.1 Motor Selection and Application

Electric motors are used to provide motive power to equipment such as compressors, pumps, blowers and a variety of diverse equipment which find application in industry. It is important that the industrial user defines his need accurately to enable proper selection of a motor for a particular application.

When selecting a motor for any application, the following points should be considered.

1. Process requirements; general, automatic/non-automatic control, variable speed, etc.;

2. Type of motor and starter;

3. Electrical system requirement; and

4. Availability, reliability, and maintenance requirements.

It is frequently observed that motors of rating higher than that required for the given applications are used. There are several reasons for this. Original equipment manufaturers tend to keep a large safety factor in selecting the motor, which results in underloading of the motor. Underloading of the motor may also occur as a result of under utilization of the equipment. For example, machine tool equipment manufacturers provide for a motor which can take up the load when the equipment is utilized to its full capacity; the user may not utilize this capacity thus leading to underloading.

Before going into some of the aspects of motor performance and means of reducing motor electricity consumption, a brief review of the factors affecting motor performance are given below.

Factors Affecting Motor Performance. The efficiency of an electric motor is the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals. The efficiency with which this transformation takes place is determined by intrinsic losses occurring within the motor; these losses can be reduced only by changes in the motor design.

Figure 1 shows the typical variation of efficiency, power factor and input current with load for an induction motor. Part-load performance characteristics depend on motor design and vary from motor to motor. For operating loads in the range of 50-100 per cent of rated load, the efficiency reduction is not very significant but the power factor drops considerably. On further reducing the load, both power factor and efficiency decrease and the effect is significant at very low loads.

Intrinsic motor losses can be categorized in two groups - no-load or fixed losses, and load or variable losses. No-load losses, as the term implies, occur even when the motor is unloaded and are relatively constant over the entire load range. The fixed losses in a motor comprise of magnetic core losses and friction and windage losses. Load losses vary with the motor load and consist of stator I^2R losses, rotor I^2R losses and stray load losses. Figure 2 shows the variation of the different types of losses with load.

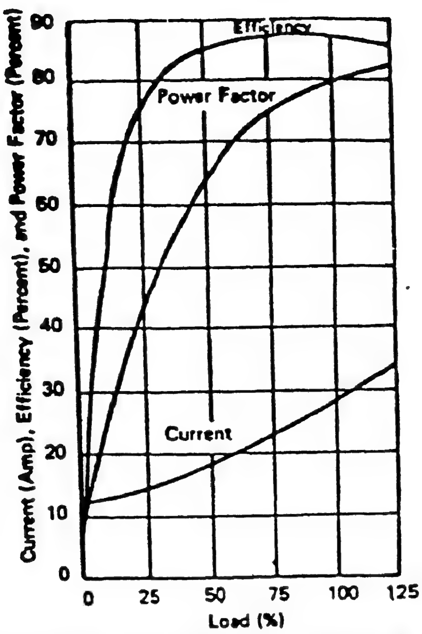

Fig.1: TYPICAL PERFORMANCE CURVES FOR DESIGN B, 10-HP, 1800RPM, 220-V, THREE-PHASE, 60-HZ INDUCTION MOTOR

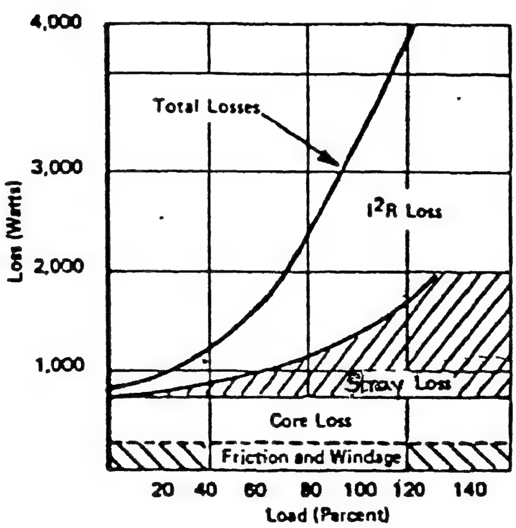

Fig.2: TYPICAL LOAD VS. LOSS CURVE FOR DESIGN B, 50-HP, 1800 RPM INDUCTION MOTOR

Magnetic core losses or iron losses consist of eddy current and hysterisis losses in the stator and rotor magnetic structure. They are independent of the load but depend on voltage, core steel material and its physical geometry. Friction and windage losses are caused by friction in the bearings of the motor and the windage loss of the ventilation fan and other rotating parts. These losses are also constant over the entire load range.

Copper losses (I^2R losses) are caused by currents flowing through a resistive path and are a function of the square of the current. Stray load losses are residual losses arising from a number of elements and are difficult to either measure directly or calculate. They are proportional to the square of the rotor current. The factors that affect different types of losses in an induction motor are given in Table 4.

Motor performance is also affected considerably by service conditions such as voltage and frequency, and voltage unbalance across the three phases. Voltage unbalance can be more detrimental to motor performance and motor life than voltage variation.

Another factor affecting efficiency is the practice of rewinding of burned-out motors. Through proper rewinding, motor efficiency can sometimes be maintained at previous levels. However, in a majority of instances, poor workmanship and poor rewinding practices result in loss in efficiency.

6.10.8.2 Results from Field Testing of Motors

Since actual operating conditions in the field are quite different from the ideal conditions for which motor specifications are given, considerable number of field tests were conducted by TERI on motors in several industries. It was seen from these tests that the operating efficiency and power factor of motors was very much lower than those specified by motor manufacturers. Figure 3 shows the average full-load efficiency of motors of different sizes as specified by motor manufacturers and as observed in field tests (corrected for full-load conditions). These results further emphasize the fact that motors in industry are not operating at optimum loads or operating conditions.

Table 3.1 Factors Affecting Losses in an Induction Motor

Iron Loss		Copper Loss		Frictional Loss	Windage Loss	Load Loss
Hysteresis loss	Eddy current loss	Stator loss	Rotor loss			
Material - hot rolled/cold rolled/cold rolled non-grain oriented steel	Conductivity of core steel	Operating load	Operating load	Bearing size and type	Type of enclosure	Operating load
Loss in W/kg of steel at operating flux density	Operating flux density	Conductivity of winding material	Conductivity of winding/bar material	Weight of rotor	Heating produced due to other losses	Overhang of winding
Slot dimensions and wedges	Lamination thickness and uniformity	Cross-sectional area of winding	Cross-sectional area of winding/bar	Type of lubricant	Type of fan - unidirectional/bi-directional	Tooth harmonics
Stator-rotor slot combination (slot harmonics)	Core packing factor	Winding arrangement	Rotor length	Temperature of lubricant	Speed of rotor	Air gap flux density
Core packing factor	Inter-lamination insulation	Length of winding	Skin effect in winding	Alignment of shaft	Physical shape and dimensions of fan	Burring of laminations
Power frequency	Stator-rotor slot Combination (slot harmonics)	Skin effect in winding	Temperature of winding	Position of shaft - horizontal/vertical		Ratio of air gap to rotor slot opening
Slip at operating load	Slip at operating load	Temperature of winding		Speed of rotor		Bonding of rotor bars to rotor laminations
Age of steel	Power frequency	Slip of rotor				
	Age of steel					

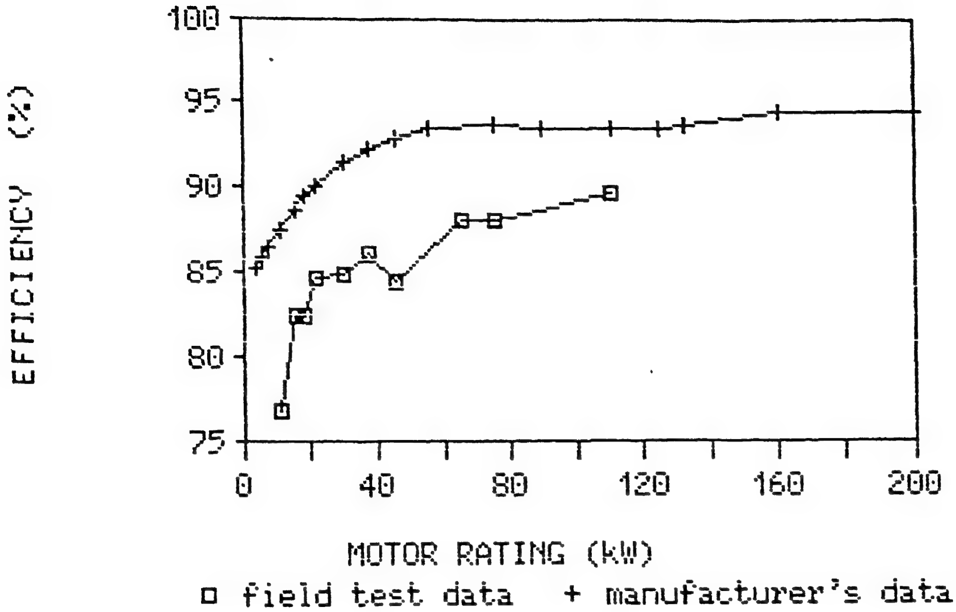

Fig.3: Squirrel Cage Motors Efficiency Vs. Motor Rating

6.10.8.3 Energy Conservation in Motors

Electricity consumption in motors can be reduced by operational improvements and retrofit improvements which are listed below.

Operational Improvements

- operate at rated voltage and balanced supply
- improve controls
- regular maintenance
- improved cooling

Retrofit Improvements

- Replacing oversized motors by motors of lower rating
- Replacing old and inefficient motors by new motors
- Replacing exising motors by energy-efficient motors
- Use of proper controls (e.g., variable speed drives, soft starters, etc.)

Perhaps the most significant savings in motor electricity could be effected by proper selection of type and rating

of motor. Underloading of motors has several disadvantages, such as:

- Lower motor efficiency
- Poor power factor
- Higher first cost of motor and control gear

It has often been observed that in many industries, motors of high ratings are selected to drive high inertia loads where special motors designed for high starting torque, but of lower rating, would have been more suitable.

For applications which have varying load patterns, it is not advisable to select a motor based only on the highest load to be taken by it. Instead, an optimum rating of motor may be selected based on the loading cycle and the time for which the motor has to operate at each load during the cycle. The optimum rating in such cases is the equivalent steady-state rating which would result in a temperature rise equal to that of the defined load cycle. The optimum rating may be calculated using the relation:

$$hp = \sqrt{\sum_{i=1}^{n} \frac{(hp_i^2 \times t_i)}{T_e}}$$

where, t_i is the cycle time for which the motor operates at a load of hp_i, and T_e is the effective cooling time for the entire load cycle; which is equal to t_i for running periods of the motor, and equal to one-fourth of t_i for the time the motor is not operating during the cycle (since there is not effective cooling during the motor off-time). It might be possible in many instances to select a motor of a slightly lower rating and operate at overload for a very short period of time (without exceeding the thermal capacity of the motor insulation), instead of selecting a motor of high rating to operate at full load for a short duration. This method of calculating the motor rating, however, is not suitable for motors subjected to frequent starts/stops and for motors operating high inertia loads.

Under operating conditions, however, it is normally quite difficult to ascertain the load on the motor to decide whether or not motor is underloaded. The load on the motor can be determined only by measuring input parameters such as power, current, voltage, speed and frequency, under both load and no-load conditions. It is not advisable to determine the load on the motor based on the motor load current alone since this could lead to misleading results. Figure 4 shows the variation in motor current for varying load for a typical 18 kW (25-hp) motor. It can be seen from the figure, that at a load current of 60 per cent, the output is only about 42 per cent of the rated value. Therefore, it is important to have adequate instrumentation to be able to conduct tests on motors to determine the operating load, operating efficiency and operating power factor.

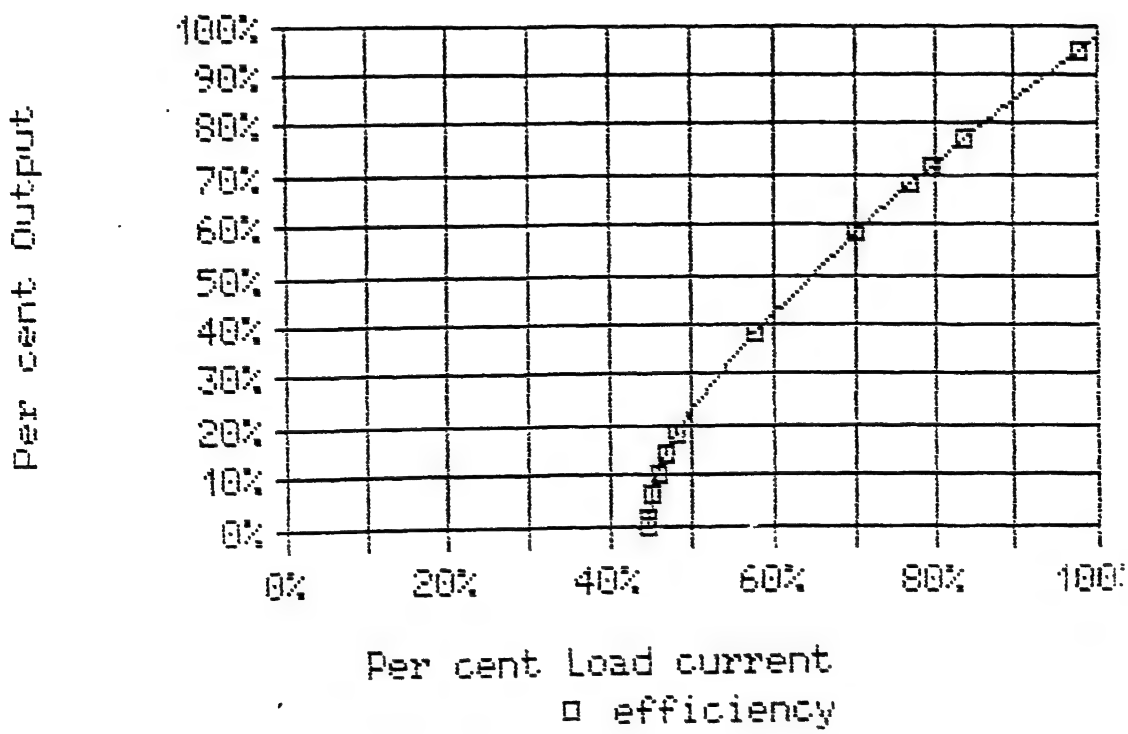

Fig.4: Output vs. load current 18 kW induction motor

Based on the results of such tests it could be determined if the motor could be replaced by a new motor (of the same rating) which would operate at a higher efficiency, or by a motor of lower rating which would operate at an improved load factor, and consequently at improved efficiency and power factor. An improvement in the efficiency by even a few percentage points could result in significant savings depending upon the operating hours and the tariff structure. Lower input results not only in lower energy charges but also in lower demand charges due to reduced kVA demand.

For example, consider the replacement of a 11-kW (15-hp) motor operating at 100 per cent load and at an efficiency of 85 per cent and at a power factor of 0.8, by a new motor also of 11 kW:

Existing Motor

Motor rating	11 kW
Operating efficiency	85 %
Operating power factor	0.8

Replace by new 11-kW motor

Operating efficiency	89 %
Operating power factor	0.85

Annual savings in electricity	4650* kWh	
Annual savings in demand	20 kVA	
Annual savings in energy charges	Rs. 4650+	
Annual savings in demand charges	Rs. 1200+	
Total annual savings	Rs. 5850	
Cost of new motor (Approx.)	Rs.11000	
Salvage value of old motor	Rs. 2750	(@25 %)
Net investment	Rs. 8250	
Simple payback period	1.4 years	

Similarly by replacing an oversized motor by a motor of lower rating, considerable savings in motor electricity consumption could be effected.

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* Based on annual operation for 8000 hours

\+ Based on a tariff of Re.1/kWh and at a demand charge of Rs. 60/kVA.

6.10.8.4 Energy-Efficient Motors

Energy-efficient motors are motors having higher efficiencies, which can be obtained by incorporating design improvements to reduce intrinsic motor losses. Motor losses can be reduced by taking several measures such as, using low-loss steel, increasing the active material by incorporating a longer core length, using thinner laminations, reducing the air-gap between stator and rotor, using copper bars in the rotor instead of aluminium, by using superior bearings and a smaller fan, etc. As a result of these modifications, costs of energy-efficient motors are also higher than those for standard motors.

Energy-efficient motors are now available in the country which have efficiencies higher by 3-4 per cent over those for standard motors. The power factor is also higher and a further advantage is a fairly flat performance characteristic over a wide range (typically 50-100 per cent) of load. These motors cost about 30 per cent more than equivalent standard motors. Even so, the savings which could be achieved at such improved efficiencies justify the additional expenditure incurred on the motor. The economics, however, depend on the operating hours and the electricity tariff. Usually, motors operating for less than 2000 h/annum are not good candidates for replacement by energy-efficient motors.

The selection of energy-efficient motors should be based on several factors additional to those for a standard motor:

1. Electric power-saving and life-cycle-cost comparison with those of standard motors;

2. Improved ability to perform under adverse conditions such as abnormal voltage (Generally, the energy-efficient motors have superior performance characteristics under abnormal voltage conditions);

3. Lower operating temperature;

4. Noise level;

5. Ability to accelerate higher-inertia loads than standard motors;

6. Higher operating efficiencies at all load points (At all loads, the energy-efficient motor presents an opportunity for energy savings,)

   In certain applications and duty cycles, energy-efficient motors cannot be justified on the basis of energy saved, for example,

a. Intermittent duty or special torque applications:

- Hoists and cranes
- Traction drives
- Punch presses
- Machine tools
- Oil fields pumps
- Fire pumps
- Centrifuges

b. Types of loads:

- Multispeed
- Frequent starts and stops
- Very high-inertia loads
- Low-speed motors (below 720 rpm)

6.10.8.5 Power Factor Correction Induction motors inherently operate at lagging power factor due to the magnetizing current drawn by the motor (which is essential for the creation of the magnetic field to transfer power from the stator to the rotor). The use of capacitors to improve the power factor has several advantages such as:

- reduced kVA demand, thereby reducing demand charges;

- reduced I^2R losses in cables, thereby reducing energy charges;

- reduced voltage drop, leading to improved voltage regulation; and

- a resultant increase in overall system efficiency.

The rating of capacitor required for a particular motor depends upon the no-load kVAR requirement of the motor, which can be determined only by conducting no-load tests on the motor. It is recommended that the capacitor kVAR should not exceed about 90 per cent of the no-load kVAR of the motor. Alternatively, a safe value of capacitor may be installed depending upon the motor rating. Table 2 gives the recommended value of capacitor to be used for standard motors with different number of poles.

Since a reduction in line current and the resultant improvements are reflected backwards from the point of application to the generator, the maximum benefit from power factor correction can be achieved if the capacitor is connected across the motor terminals.

However, this is subject to the economics of installing low rating capacitors, and the savings that could be

achieved by their installation. It should be ensured that capacitors of higher ratings than those required are not installed since this could result in over-voltages which could cause the motor to burn-out. Adequate protection should also be provided for the capacitor to discharge when it is switched off.

6.10.8.6 Other options for electricity saving in motors

Variable Speed Drives. Most motoring applications of electric machinery require either a constant speed or operation over a continuous or discrete range of speeds. Discrete number of speeds can be achieved by pole-change windings which are obtained by switching the windings of the machine in banks or groups to produce different number of poles.

Continuously variable speed drives, on the other hand, have traditionally been the domain of DC machines. However, the emergence of solid-state frequency changers (inverters, cycloconverters and the like) have permitted the operation of AC motors with adjustable speed.

Variable speed drives are increasingly finding applications in ID fans, large pumps, mill motors and cement kilns. In addition to the advantages such as operation at constant torque, variable torque, high starting torque and soft-start features, variable speed drives offer considerable opportunities for energy savings for motor operation at low speed.

Other options available for savings with variable speed applications are: adjustable speed pulley systems, eddy-current drives, fluid drives and slip recovery systems.

Use of Flat Belts for Transmission Drives: Transmission drives such as pulleys and belts, and gears transmit mechanical rotational power from the prime mover shaft to the shaft connected to the mechanical load such as a compressor, blower or a fan. The simplest form of transmission drive is the belt drive which is least expensive, light and quiet in operation. The belt drive transmits power solely by the frictional grip between the belt(s) and the pulley. The belts consist of tension strands which serve to absorb the tractional forces operating in the belts, which are covered with an elastomer. The elastomer holds the strands together and provides surface friction for power transmission.

In many conventional belt drive systems, V-belts are normally used. New materials have made possible the manufacture of flat belts with better performance characteristics. Unlike the V-belt that develops additional lateral frictional forces, the flat belt develops only

the tangential forces. This reduces the stress on the (flat) belt and results in lower heat generation due to lower lateral compression and elongation. Moreover, flat belt is free from the effect of heating at the edges that results in hardening of rubber and reduction in the frictional grip.

Due to the higher transmission efficiency of flat belts, savings in the range of 5-12 per cent can be achieved in the motor input power (10-12 per cent savings have been practically achieved in industries where flat-belts have been used). The payback period is normally less than one year.

Air-Compressor Drive Systems. Proper operation of air compressors results in a reduction of motor electricity consumption. It has been observed in many instances that the air suction lines are located within the compressor room, which results in the suction air temperature being higher than the ambient temperature.

Typically, a 3^{o}C rise in inlet air temperature results in one per cent additional energy input for the same compressed air output. Therefore, it is advantageous to provide extension pipes to the air inlet suction pipe such that the air intake is outside the compressor room and at ambient temperature.

Cooling Tower Fans. Fibre reinforced plastic (FRP) cooling tower blades are now available which have optimal strength, weather resistance and durability characteristics. The efficiency of large cooling towers fans depends much upon the blade profile and its surface finish. In the case of aluminium blades, the efficiency of the fan is low due to certain design/manufacturing limitations. The efficiency decreases in course of time due to erosion and corrosion of aluminium blades. In comparison, FRP blades remain unaffected throughout its life as the blades are highly corrosion resistant. Also the total weight of the fan assembly with FRP blades is much less than that with aluminium blades. Therefore, the thrust load due to the dead weight of the fan gets considerably reduced and thereby increases the life of the gear box.

Energy savings of up to about 15 per cent could be achieved with the use of FRP blades for cooling tower fans. However, the cost is high and payback periods are in the range of 3-8 years.

6.10.8.7 Maintenance

A large number of equipment and processes in industries are dependent on the electric motor for their operation.

It is, therefore, essential that motors be properly operated and maintained to ensure reliable and efficient operation. Motor losses increase significantly without proper maintenance. For example, improper lubrication can cause increased friction in both the motor and associated drive transmission equipment; the electrical resistance of conductors increases with temperature which results in increased copper losses in the motor. By providing adequate ventilation and by keeping motor cooling ducts clean, heat can be effectively dissipated, thereby reducing energy losses and also increase the life of insulation (for every 10^{o}C increase in motor operating temperature over the recommended hot spot temperature limit, life of the winding is reduced by half).

The list below shows some of the important items that should be checked regularly to ensure proper motor operation:

- Inspect motors regularly (at least annually) to detect wear in bearings, housings, and for dirt and dust in motor ventilating ducts

- Check load condition to ensure that the motor is not over or underloaded. A change in motor load from the last test indicates a change in the driven load, the cause of which should be identified and corrective action taken as needed. Load tests can be conducted at the time of normal motor inspection or on a continuous basis if permanent instrumentation is installed.

- Take extra care in lubrication. Motors should be lubricated in accordance with the manufacturer's recommendations, but care should be exercised not to over-lubricate. Excess oil or grease from the motor bearings can enter the motor and saturate the motor insulation, causing premature failure and a possible fire.

- Watch alignment. Check periodically for proper alignment of the motor and the driven equipment. Improper alignment can cause shafts and bearings to wear quickly, resulting in damage to both the motor and the driven equipment.

- Be sure that the supply wiring is properly sized and installed. At regular intervals (usually annually), inspect the connections at the motor and starter to be sure that they are clean and tight.

6.10.8.8 Conclusion

It can be seen from the above discussion that there is considerable potential for effecting savings in motor electricity consumption by employing various measures, both long-term - changing the motor, replacing by high efficiency motor; and short-term - proper maintenance, operational improvements, installation of capacitors.

However, the deciding factor in employing any measure to effect energy savings would be the economic incentive provided by it; which in turn, would depend on the commitment of the management, the management's priorities for investment and the tariff structure. It is recommended that the effectiveness of any energy-saving measure be calculated on a life-cycle costing basis, instead of using the simple payback period as a measure. It is also useful to keep in mind the increase in costs of energy in making these calculations.

6.10.9 Electric Heating and Electrolysis

Most industries require some form of material heating for process purposes. Electric heating has certain unique characteristics which makes it very suitable for industrial applications. Some of these characteristics are:

(i) The precision of electric control is extended to the transfer of heat. Uniformity of temperature within a relatively narrow limit is readily attained.

(ii) Heat generation does not involve combustion.

(iii) There is no upper limit to the temperature attainable except the ability of material to withstand heat.

The collateral merits of electric heating vary with the conditions in each case. The most important of these are:

(i) application at the precise point needed;

(ii) flexibility - includes easy subdivision, freedom of location, and general adaptability;

(iii) good working conditions, cleanliness, quiet operation, little effect on ambient temperature, etc.;

(iv) fast response; and

(v) safety

The various forms of electric heating used in industry are:
(i) Resistive heating
(ii) Infrared heating
(iii) Induction heating
(iv) Electric arc heating
(v) Dielectric heating

The heating method for a particular process may be selected after consideration of two basic principles of industrial heating - temperature and mode of heat transfer.

Though this narrows the field from which a choice of the heating method could be made, there is generally more than one possible method. Economic factors such as relative capital costs, maintenance costs, and energy costs also influence the decision.

In electric furnaces, resistance and induction methods are widely employed. The use of electric arc is generally confined to high-temperature applications. Dielectric equipment is used for the heating of non-conducting materials such as wood, paper, ceramics, rubber, glues and resins.

Resistive heating. Resistance heating may result by the direct application of current to the charge or work piece. The workpiece provides a resistive path to the current flow, with heating taking place by the I^2R effect. Heat transfer can also be effected by convection or radiation by placing the work piece in an enclosure (heating chamber).

The resistor material is determined by the temperature to be attained. For temperatures above 1150°C, resistors of silicon carbide, molybdenum, tungsten and graphite have to be used. The temperature attained is a function of the surface power density (watts per unit area) and therefore, a variety of controls may be used to attain the required temperature.

Resistive heating is used in a variety of small devices such as electrically heated tools, water heaters, sterilizers and baths. Larger units include ovens, kilns, furnaces, etc.

Infrared heating. In this method, heat is transferred through radiation using tungsten filament lamps with reflectors. A large part of the radiation of tungsten lamps is in the infrared region of wavelength, hence the term infrared heating.

Infrared heating is generally used for drying and baking processes which require temperatures below 600°F (315°C) and for surface heating as in case of textiles, paper, etc.

The radiation on the charge depends on the wattage, spacing of lamps and efficiency of lamp reflector units. The temperature attained by the charge is dependent on the time of exposure, power concentration, absorption coefficient of surface of charge, thermal properties of the charge and heat loss from the charge due to reradiation and from the chamber.

Induction heating. In this method, the material to be heated is exposed to an alternating magnetic field. The material to be heated must be a conductor so that currents are induced in it. Factors which affect the rate of heat development are the electric and magnetic properties of the material, the frequency and the radius (or depth) of charge.

Due to skin effect the surface of the charge gets heated to a greater extent than the inner mass. The penetration is inversely proportional to the frequency and therefore low frequencies have to be used with large pieces and high frequencies for small work pieces. The criterion for the selection of frequency is also dependent on the resistivity and shape of the charge material. The efficiency with which the charge is heated decreases if the length is not substantially greater than the cross-section.

Induction heating can be used for mass heating, e.g., for forging and annealing and for surface or localized heating, e.g., heating steel for hardening.

Electric Arc Heating. Arc heating utilizes electrodes placed over the charge. Heat is generated by an arc sustained between the tip of each electrode and the charge. This form of heating is normally applied in arc furnaces for the production of alloy steels and non-ferrous alloys.

Dielectric heating: In dielectric heating, electrostatic fields are used to generate heat in a material placed between two symmetrical plates. A high frequency field applied between the plates causes distortions in the molecular structure of the material, thus producing heat internally. This method is used for heating to moderate temperatures, materials that have low thermal conductivity such as rubber, wood, paper, glues and resins.

Induction and electric arc heating are normally large power consuming equipment and their operation is not as simple as that of resistive or infrared heating. However, there are certain measures to reduce electricity consumption which are applicable to all these methods. Energy conservation in electric heating is possible mainly by:

(i) Reducing heat losses

- insulate furnace walls, ducts, pipes
- put covers over open tanks or vats
- reduce the time the doors are open
- shut down when not in use or lower temperature

2. Using more efficient equipment or processes

- use alternative processes (e.g., infrared instead of resistive heating, where applicable)
- employ pre-heaters
- use direct fired rather than indirect fired systems
- use less energy-intensive materials in processes
- reduce moisture content mechanically in materials used in drying processes
- use processes requiring lower temperature

Electrolysis: Electrolysis involves the movement of positively or negatively charged ions within an electrolyte between an anode (positively charged electrode) and a cathode (negatively charged electrode). Processes which involve electrolysis include:

- Storage batteries
- Refining of metals such as aluminium
- Plating and anodizing
- Fuel cells

However, the greatest users of energy in this field is in primary metal production, particularly aluminium and magnesium. Electrolysis is also widely used in the chemical industry.

Some of the measures which may be taken to effect savings in electricity consumed in electrolysis are given below.

a. Storage batteries

- provide adequate maintenance (replace electrolyte, clean terminals, etc);
- use efficient charging techniques; charge at proper rates
- avoid overheating; provide adequate ventilation

b. Electrolytic processes

- insulate plating tanks;
- proper maintenance of electrodes and rectifiers;
- recover waste heat;
- use efficient rectifiers (silicon instead of mercury arc);
- use efficient controls;
- develop improved electrode design and materials to increase efficiency;

6.10.10 Electrical energy conservation by process modification

Production efficiency is achieved when the cost of energy, labour and material inputs per unit of product produced is minimised for a prescribed level of quality and performance. In the industrial sector, decisions must be made on the cost effectiveness of any product, process, or facility design modification.

Until recently, efficient energy utilization has often knowingly been penalised at the expense of increased operating cost in the interest of lower initial investments. As a result, process equipment and facility design modifications have generally been realised to the exclusion of improved energy efficiency, and more often than not, established production practices are wasteful of energy.

There are various methods by which the energy input per unit product manufactured can be reduced. For example, the energy required to process and finish metal products depends upon decisions made by the product designer. It is at the design stage that processes can be selected to use energy efficiently.

Many processes require pre-heating and post-heating and the merits of alternate cold processes should be considered. Heat treating processes such as carburisation are extremely energy intensive. Instead, the use of induction heating for surface hardening may be considered where possible. Similarly, pre-hardened and pre-annealed steel should be specified wherever possible, since steel mill operations are generally more efficient than individual plant operations.

Paint finishing in industrial operations often leads to inefficient utilization of energy. Paints are normally solvent based and require elevated temperatures for drying in ovens which normally have low efficiencies. An alternative to this could be the use of powder coating in which no solvents are used. Also in powder coating very little paint is wasted and the powder painted parts can be cured rapidly in infrared ovens which require very much lower energy compared to standard hot air systems.

Hot forgings may require a work piece to go through several heat treatments. Cold forgings with wrought alloys may offer a replacement. In addition, lowering the pre-heat temperatures may provide an opportunity for savings.

Forming operations can be made more efficient by employing stretch forming. In this process, the material to be formed is stretched by 2 - 3 per cent prior to forming making the material more auctile and thus reducing energy consumption in the forming stage.

Welding operations can also be made more efficient by the use of automated systems which require less energy as compared to manual welding. Automatic welding processes have the added advantage of reducing the no-load running time of the welding equipment.

Machining is not particularly energy intensive. However, machining process generally produce the most scrap. Powder metallurgy generates least amount of scrap but parts must be sintered which is usually accomplished in inefficient furnaces. Induction sintering, however, will reduce energy requirement. Scrap recycling programmes should be initiated wherever possible, not only to reduce costs but also to improve overall energy efficiency.

The designer must consider the materials selected for the part or finished product. Energy costs in the selection of materials should be considered at the design stage itself.

6.10.11 Computer Management and Simulation

Computers can play a major role in the management of energy. In many large industries, energy utilization can be complicated, involving many mutually intracting forces with complex demand patterns.

Computer techniques can be applied to two major areas of energy management:

- to actively interact and control industrial operations; and

- to simulate plant operations and energy flow

The interactive computer system can monitor fuel and power demand within the plant and either display the information for manual control of operations or actively control the plant operation and energy use according to predetermined levels. Computer control can assist in the dispatching of power supply to the fluctuating demands of the plant and can be used to control a plant load management programme.

Computers are also invaluable in analyzing plant energy data which could be used to conduct a systematic energy analysis.

Plant simulation models can be useful in the management of energy utilization in a facility. The plant energy system is modelled using engineering principles along with regression analysis of actual data from plant performance. Individual components and processes can be described by mathematical expressions related to the energy parameters. Such a simulation model could be effectively used to design an energy management programme.

6.10.12 Instrumentation and Monitoring

Instrumentation is vital to the actual measurement of energy flows and in determining energy efficiencies. Adequate instrumentation should be provided at all major equipment and feeder distribution points. This would enable monitoring of energy flow in different equipment and help in recording the energy usage pattern. Such information would be also be helpful in conducting energy audits on a regular basis.

However, it must be noted that instruments remain accurate only if they are adequately maintained and regularly calibrated. Without proper instruments to measure energy flows, energy conservation measures will be difficult to conceive, design and implement.

Operation and Maintenance

In most industrial operations, embarking on an energy management programme, the immediate savings in energy utilization can be achieved by minor improvements in the operation and, above all, through the implementation of an effective maintenance programme.

Maintenance efforts, traditionally have been motivated primarily by the concern for preserving equipment. Energy use has not been given due consideration. However, the increasing costs of electricity dictate that this deficit be remedied. Maintenance programmes can provide the framework for organized reduction in energy-consumption. Normally, maintenance could be preventive or corrective. **Preventive maintenance** has scheduled downtimes for routine cleaning, repairs, etc. In **breakdown maintenance,** equipment is operated for extended periods of time with maintenance called for only when equipment shows clear signs of impending malfunction. The latter approach wastes energy, because equipment is operating at reduced efficiency for part of the time.

Maintenance could also be predictive. **Predictive Maintenance** skirts both these pitfalls; it slashes costs and saves energy. The approach requires taking key measurements, along with a sure knowledge of how the equipment should be operating for the conditions existing. In essence, it is very simple; the process is carefully monitored; when performance begins to tail off, the deterioration is recognised and probable reasons pin-pointed. Maintenance is then needed, but it can be scheduled in between the extremes of routine and contingency conditions.

A proper combination of preventive maintenance, predictive maintenance and corrective maintenance, and cleaning and inspection of equipment can effect significant energy savings.

Projects

1. Perform a detailed analysis of aggregate electrical energy consumption for the last 12 months in the plant/workshop to identify major deviations and reasons for them.

   Repeat the analysis for daily data for one month. If electrical energy consumption data is available for systems/equipment (disaggregated), perform similar analysis.

2. Analyse the electrical loads in your plant and characterize them by end-use and functional areas. Record hours of operation and other operational and design parameters which affect the energy consumption, and estimate electricity consumption in different equipment/systems/areas. Compare these with actual consumption and decide on norms/targets for energy consumption.

3. Identify electrical instruments required for different energy-intensive systems for measurements of electrical energy related parameters within the plant workshop and provide justification for installation.

   Develop proformas for electrical energy-related data collection and reporting.

4. Identify areas in your plant/workshop where electrical energy can be saved and propose conservation measures with results of techno-economic analysis.

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Section 11: Instrumentation

6.11.1 Introduction

The importance of instrumentation in the day-to-day operation of an industry has been well recognised. Much of the progress which has been achieved in almost every field of science and technology has been due to effective instrumentation. The science of instrumentation and automatic control has advanced considerably in the last two decades.

Almost all the products that are manufactured in industries undergo some sort of a process which is closely regulated within narrow limits. Some of the variables which are measured and controlled are temperature, pressure, humidity, and flow rates. For proper regulation of manufacturing processes, not only instruments but also some sort of automatic control of the processes are required as these will help in the stabilization of process variables and increase product quality, decrease rejects and wastes, and save energy. Also the instrument relieves the operator of some monotonous and repetitive jobs, and affords him time to carry out intelligent supervision of the process. It is not enough if a plant is elaborately instrumented - it should be intelligently instrumented. Only then will it be possible to control the quality of the product within narrow limits.

Instrumentation cuts manufacturing costs and thus lowers the cost of the product to the consumer and maintains strict control over the quality of the products.

Instrumentation is one of the inevitable tools for energy conservation. It is rare that after a few years of installation equipment operates at the original conditions of purchase. It is commonly observed that improper maintenance and incorrect calibration of instruments lead to wastage of energy which is entirely avoidable. We need to know not only if equipment and systems are running but how they are working, under what conditions they are produced, their capacity, and physical characteristics.

One of the most important advantages of instrumentation, is that intelligent use of it enables many complex processes to occur simultaneously by providing instantaneous coordination and control.

6.11.2 Reasons for Measurements:

1. An equipment rarely operates as originally designed or installed. This is especially true with volume, temperature and pressure. Therefore, it is important to monitor the operating parameters of piece of equipment or a system, either periodically or continuously dpending upon the criticality of such measurements.

   Instruments are normally used:

   - to determine equipment and systems efficiencies periodically and take corrective action.

   - to find out if there is waste heat available for utilization, excess cooling, too much air exhaust, or high water consumption, etc.

   - to assist in determining if improvements in existing equipment operation is possible.

6.11.3 About Instruments

1. All instruments should be properly calibrated to be an effective tool. There are a number of standard methods of calibrating instruments. Calibration is a periodic function, and should be done at a fixed interval depending on the type of instrument, and experience with the use of instruments.

2. The quality of the instrumentation should be good and of rugged construction. If battery operated, batteries should be new or should be checked for full voltage operation. Just because an instrument may have a digital readout does not mean it is accurate or of good quality.

3. Personnel using instruments should have knowledge of how to use them and how to interpret the readings. Just getting a tabulation or readings without the knowledge of exactly where the readings were taken, the condition of a process, or the elapsed time of measurement, etc. may make this work meaningless.

4. Handling procedure of similar instruments should be standardized whenever possible.

6.11.4 Types of Instruments

1) Temperature

a) Calibration methods - ice, steam, metal freezing point.

b) Accuracy - Note that most instruments have limited accuracy. A common thermometer has an accuracy of $\pm$ 2 degrees: pyrometers - depending on the type -1 to 20 degrees. Since most readings are made in large volumes or in variable processes, this accuracy appears to be satisfactory for most use.

c) Types of temperature measuring instruments:

- Liquid filled thermometer (alcohol or mercury)
- Bimetallic element
- Electronic, thermistor, and resistance type
- Thermocouple
- Infrared and thermograph

2) Pressure

a. Calibration by means of liquid-filled manometers or special gauge testers.

b. Types of pressure measuring devices:

- "U" tube or inclined (tube) manometers
- Bourdon tube gauges
- Piezo electric and electronic equipment

3) Flow

a. Calibration of air and gas flow by means of calibrated orifices in a duct systems indicating pressure drop.

Calibrated propeller type devices can be used.

Liquid flowmeters are calibrated by orifice plates or by volumetric container devices.

It is important to calibrate flow measuring devices regularly. Errors as high as 20 per cent on steam line orifice plates, and on gas and oil meters has been experienced. It is rare that orifice plates are taken out of a pipe line for checking.

b. Flow measuring devices

- Air and gases:

  Electronic thermal anemometers
  Vane anemometers
  Pitot tubes
  Orifices
  Displacement meters

- Liquid:

  Orifices, flow nozzle, displacement meters, rotary and turbine type devices, pitot tubes, and timed containers

- Solid:

  Scales and containers

4. Moisture: Measurement by wet- and dry-bulb thermometer, electronic absorption resistance devices, and optical radiation units.

5. Chemical: Field measurements can be made by calorimetric devices for reasonably accurate measurements on many materials. Suspended atmospheric particulates are measured by high volume samplers. If higher accuracy is required, EPA* procedures must be used or a colorimeter or mass spectrograph analysis is required.

6. Speed: Driven tachometers or stroboscopes

7. Electrical Parameters: Light meters, ammeters, voltmeters, power factor meters, time cycle clocks, watt meters and energy meters.

8. Recorders: Continuous readings of various parameters may be required by certain equipment or systems. Round-chart and strip-chart recorders are available for this purpose and are very useful in determining conditions, especially over measured periods of time and when no personnel is present to make continuous readings.

Portable Instruments

These days sophisticated digital portable instruments are available for measuring energy related parameters in industries. These instruments are very useful for quick measurements and corrective action. These are broadly classified as thermal instruments, electrical instruments and general instruments.

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* EPA - Environmental Protection Agency, U.S.A.

The Tata Energy Research Institute, New Delhi designed and developed the first energy bus in the country, called the Encon Bus (Energy Conservation Bus), for conducting on-the-spot energy audits in small- and medium-sized industrial units. Encon Bus is a van carrying portable instruments for measuring thermal and electrical energy flow and energy related parameters. Table 1 provides a list of instruments in the Encon Bus.

Table 1

List of Instruments in Encon Bus

Instrument	Specifications: Working Range	Specifications: Accuracy
A. Thermal Instrumentation		
1. Portable digital, battery-operated temperature indicator along with probe, suitable for:		($\pm$0.5%$\pm$1 digit)
Surface (flat or curved	- 50° to 600°C	
Liquid or gas	- 50° to 1200°C	
2. Portable carbon monoxide/oxygen analyser cum temperature indicator (Portable combustion optimizer) along with probes and spares like sensors and filters	Carbon monoxide:0-3999 ppm Oxygen:0 - 20.9% Temp. :999°C	CO:$\pm$2.5% O_2:0 to$\pm$4% Temp.:$\pm$1%
3. Portable fyrite indicator for flue gas analysis (combustion test kit)		0.5 to 1% of scale reading
4. Heat flux monitor for monitoring heat flux,used for detection of insulation defects, heat loss through walls and doors of furnaces, etc.	-29° C to $\pm$1093°C	1°C
5. Infrared pyrometer	0° to 1000°C	
6. Chromopens and pyrodots	$\pm$ 50° to $\pm$ 1600°C with different intervals	$\pm$1 %

Contd.

Table 1 (Contd.)

List of Instruments in Encon Bus

Instrument	Specifications: Working range	Specifications: Accuracy
7. Ultrasonic trouble shooter for steam trap leakages	Ballistic Meter	
8. Steam stethoscope for checking condition of steam traps and detecting leak		
9. Portable thermohygrometer	5-98% (RH) -10 to 70°C	±2% RH approx.0/5°C at ambient temp.
B. Electrical Instrumentation		
1. Digital multimeter	1000 V(DC),750 V(AC) 10 A, 0-2 M	
2. Power multimeter to measure V,I,kW,pf,kVA,kWh,kVAR,kVAh, kVARh phase sequence, firing angle, inrush current	600 V,1000 A(AC), 1800 kW(3), 0-9999 kWh	
3. Clamp-on type ammeter and voltmeter	1000 A, 600 V	
4. Current transformers of different ratings	different ratios (1000/5,100/5,30/5)	
5. Digital frequency meter	40 - 60 Hz	
6. Digital milliohm meter	0 - 2 M	
7. Motor checker for winding resistance and inductance	0 - 30 , 300 Henry	
8. Lux meter	0 - 30,000 Lux	
C. General Instrumentation		
1. Stop watch		
2. Portable pH meter	0-14	(0.02 ± 1 digit)
3. Portable conductivity meter	200-20,000 micro MHOS	± 3%
4. Air velocity meter or anemometer	0-30 m/sec (at 0° to 70°C)	Velocity: ± 2% FSD Temperature: 3% FSD
5. Digital tachometer	60 to 19999 rpm	± 1 to ± 3 rpm

FSD - full-scale deflection

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1. Patranabis, D., Principles of Industrial Instrumentation, Tata McGraw - Hill Company, Bombay (1976)

2. Doebelin, E.O., Measurement System, McGraw-Hill, Auckland (1983)

CHAPTER 7

SOLAR ENERGY FOR INDUSTRIAL APPLICATIONS

CHAPTER 7

SOLAR ENERGY FOR INDUSTRIAL APPLICATIONS

7.1 INTRODUCTION

It is known that fossil fuels are exhaustible. For a country like India, the fossil fuel resources, viz., of coal and hydrocarbons are limited, and it is increasingly more expensive to extract every additional tonnage of these energy sources. The major option India has today is to manage its energy resources both at the supply and end-use points. In this respect energy conservation and renewable energy sources wherever they are applicable become important.

The conventional sources of energy like petroleum and natural gas are limited and may be exhausted by the end of the present century or beginning of the next century while coal is expected to last 150-200 years. Tapping nuclear energy presents safety hazards due to radioactive fallout and disposal of nuclear waste. Solar energy with its pollution free, continuous and constant supply and without safety hazards may be the solution to the energy problems of the future.

In a developing economy, energy consumption per unit of value added in the industrial sector is relatively high compared to that in other sectors. In India, for example, about 35 per cent of the total available commercial energy is consumed in industry. It is estimated that a large fraction (60-70 per cent) of all the energy consumed in industry is in the form of thermal energy (process heat). Thus, there is a great potential for utilizing solar energy for low-grade industrial process heat (IPH), especially in tropical countries like India where solar radiation is abundant. Unlike the space heating or domestic hot water (DHW) applications, the demand for IPH is nearly constant throughout the year and hence, the capacity utilization of solar systems for IPH can be very high.

7.1.1 Solar Energy

There are several factors which have to be examined critically for making the best use of solar energy for IPH. Firstly, solar radiation is a dilute source of energy with peak intensities of about 1 kW/m^2. On the other hand, the energy-use intensity is quite high in industry, which means that large areas are needed for collection of solar energy. The non-availability of large areas for installation of solar collectors can be the single major constraint for industries located in

densely populated areas. Secondly, there is a wide fluctuation in solar radiation, both diurnal and seasonal, which necessitates storage of thermal energy and/or a back-up system using conventional energy sources. The need for a large surface area of collectors and the need for sensible heat storage are mainly responsible for the high initial costs of solar systems. Thirdly, the complexity and cost of solar thermal systems increases with increase in the temperature at which thermal energy has to be delivered. In theory, solar energy can be supplied in any form required by industry. In practice, because of an inverse relation between operating temperature and solar system efficiency, the use of solar energy is currently most cost-effective at low or intermediate temperatures (less than 275°C). However, at least 30 per cent of industrial process heat requirements fall in this temperature range. If preheating to 275°C for higher temperature requirements is considered, a little over 50 per cent of industry's process heat can be supplied by available solar equipment. Despite the sensitivity of solar thermal system efficiency to operating temperatures, it is clear that a large share of industrial process heat can be supplied by the sun.

7.1.2 Potential

Heating is one of the major applications of fuel use in industry, and as significant amount of energy is utilised at relatively low temperatures, premium fuels are not really required. A recent study in U.S. on industrial energy demand revealed that about 7.5 per cent of the total heat is used at temperatures below 100°C and about 23 per cent below 300°C. Also, it was found that if preheating is employed, about 27 per cent of total energy for industrial heat could be delivered below 100°C and about 25 per cent below 300°C.*

An analysis of the energy use pattern in U.K. industries shows that about 33 per cent of all end-use energy requirements could be completely satisfied at temperatures below 120°C, and almost two thirds of it below 80°C.

A study of the Australian food processing industry showed that thermal energy comprised 90 per cent of the industry's total energy needs, almost all of it below 150°C and about 80 per cent below 100°C. A similar study of the soft-drink plants showed that 70 per cent of their heat requirements could be supplied at low temperatures. This demonstrates that if specific industries are selected through detailed investigation, low-grade thermal energy requirements may be remarkably higher than those estimated so far.

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* Similar data for Indian industry is not available.

It is ironical that countries blessed with some of the biggest reserves of fossil fuels and lying in the higher latitudes are actively pursuing efforts to substitute conventional energy with solar energy to the maximum possible extent, while India which neither has substantial reserves of oil nor a well-developed coal industry, but is lucky to be located in the sun-drenched tropics, has not yet fully explored the potential for its utilization.

In this Chapter, an assessment of the requirements for low-and medium-level heating applications in the Indian industry is presented, and the extent to which these can be potentially met through solar thermal devices, which are either currently available or expected to reach the local market within the next few years is discussed. The economics of such a substitution and potential benefits to the society have also been examined.

7.2 HOT WATER APPLICATIONS IN INDUSTRY

A large number of industries require either hot water or steam for their processes. Hot water is also necessary for heating; drying; cleaning clothes and vessels; in heat exchangers; washing filtered cakes; digestion; dissolution; precipitation; dilution; curing of tyres and tubes; calendering, etc.

In textile industry, hot water is required for washing yarn, bleaching, dyeing and mercerizing. It is also required in fruit processing and paper industries for making fruit pulps and paper pulps respectively. Other uses are in paddy parboiling and in the dressing and processing of minerals.

Preheating of boiler feed water is an important low-level heating load in process plants. Generally, 5-15 per cent make-up water of total steam load is required to supplement the condensate recovery system. In principle, solar energy can be used for preheating the boiler make up feedwater, though it has to be first ascertained whether more economic waste heat recovery techniques are possible.

7.3 QUANTITATIVE REQUIREMENTS

In the absence of any comprehensive official study in India along the lines mentioned above for U.K. and U.S.A., we have to depend on random assessments or sample surveys. A study conducted by the National Productivity Council identified certain industries among the potential consumers of low- and medium-temperature hot water/steam. These industries are listed in Table 1.

Table 1

Hot Water/Steam Requirements for Selected Products (tonnes per tonne of product)

01. Hydrogenation of oil	0.5, steam
02. Soap	0.8, hot water
03. Sucrose	3.4, hot water
04. Ethyl alcohol	12, hot water
05. Wood pulp	0.13, hot water
06. Industrial alcohol	5 kg, steam, and 10 kg, hot water per L product
07. Sodium carbonate	1.6, L.P. steam and 1.36, H.P.steam
08. Urea	2, steam
09. Vinyl chloride	2, steam
10. Caustic soda	9, steam
11. Cotton seed oil	0.8, steam
12. Soyabean oil	3, steam
13. Nitric acid	1, steam
14. Oxygen	1.75, steam
15. Rayon yarns	48, hot water
16. Soda ash	1.6, hot water

Table 2 lists the temperature requirements of a typical cotton mill, rayon factory, pharmaceutical company, a chemical manufacturing concern, a dairy, a fertiliser industry and a food processing unit. The above lists are by no means exhaustive, but the data thus gathered has helped to build Table 3 in which assessment regarding the potential requirements of low-and medium-temperature hot water in the Indian industry is given. The estimates given in Table 3 are approximate, and useful only for an order of magnitude analysis.

Table 2

Hot Water/Steam Requirements of Some Typical Industrial Units

Type of Industry/ Product	Hot Water/Steam Requirement, tpd*	Type and Quantity of Product
1. Cotton textile	Hot water 500 tpd at about 75°C	Cotton blended cloth. About 12,500 m/day
2. Rayon factory	Hot water, 2300 tpd at 60-95°C	Rayon yarn and tyre cord, 50 tpd
3. Pharmaceuticals	Hot water & steam 12 tpd at 60°C to 80°C	Pharmaceuticals
4. Chemicals	Hot water 140 tpd at 70-80°C	Dyes, Chemicals
5. Tyre factory	Steam 100 tpd at 175°C	Tyres, tubes, etc. 65 tpd
6. Dairy	Hot water & 600 tpd at 24-90°C	
7. Fertilizer Factory	Hot water steam 11000 tpd at 68-105°C	
8. Starch products	Hot water 200 tpd at 50°C	
9. Maize products	Hot water 800 tpd at 50°C	

* tpd - tonnes/day

Table 3

Approximate Hot Water/Process Steam Requirement for Industry

Type of Industry	Hot Water Consumption (t/t)	Annual Production (t)	Total HW requirement (tpd)
01. Soap	0.8	300,000	800
02. Soda Ash	1.6	600,000	2,500
03. Chlorine	11	260,000	8,000
04. Vanaspathi	0.5	400,000	600
05. Vinyl chloride	2	500,000	3,000
06. Aluminium	6	300,000	5,000
07. Caustic Soda	9	600,000	15,000
08. Rayon yarns & manmade fibres	48	116,000	26,500
09. Cotton textile	-	8.3×10^9 m	60,000
10. Tyres	-	5×10^6 units	1,500
Others including fertilisers, food products etc. (approx.)			80,000

HW - Hot water

7.4 APPLICATIONS

In India, the application of solar energy to IPH has so far been constrained by the availability of only indigenous solar technology. Only the flat-plate collector technology is well developed. There are several manufacturers (Appendix 1) capable of supplying solar hot water/hot air systems of large capacities. As the temperatures achievable by this technology are limited to about 80°C, only those applications which require hot water or hot air at or below 80°C are relevant. Evacuated tubular collectors with delivery temperatures of about 150°C are now on the horizon*. These systems are applicable in situations where low pressure steam is required. Based on these considerations, the various categories of industries where solar IPH are feasible are discussed below.

* At present, evacuated-tube solar collectors are available from IBP Co., Bombay. These collectors are imported from Fournelle, Canada.

7.4.1 Dairy Industry

The growth of dairy industry in India, particularly in Gujarat has been very significant. The total average daily throughput of 203 dairies in 1981-82 was about 7 million litres of milk. Two types of milk processing plants are in use in the country - one where milk is pasteurised and packed for distribution and the second where products like milk powder, ghee, butter, etc. are produced. An estimated 33 per cent of the milk processed in dairies is converted into milk products while the rest is sold as milk. The thermal energy consumed in processing and packing of 100,000 L of milk is estimated to be about 1.2 tonnes of oil equivalent. The production of milk products, on the other hand, is far more energy intensive. For conversion of 100,000 L of liquid milk to milk powder, the energy requirement is about 5.1 toe. Thus, the thermal energy requirements of the dairy industry in India would work out to be about 62,000 toe per year.

The primary step in milk processing is pasteurization. Pasteurization is carried out at 85°C, but due to the regenerative nature of the process, the net thermal energy consumption of about 25 per cent of the total energy is needed for processing. Thermal energy is mainly consumed in bottle and can washing and together these two operations account for the remaining 75 per cent of the energy required. The temperature requirements for these applications vary from 65°C to 90°C and these can be met with the presently available flat-plate collector technology.

7.4.2 Textile Industry

Textile industry is one of the largest energy consuming industries in India. Of the total energy consumed in a textile mill, about 90 per cent is in the form of thermal energy (steam) and the rest is in the form of electricity. Hot water below 90°C is used for the following applications within a textile mill: boiler feed, rope washing, kier boil, bleaching, cloth mercerizing, yarn mercerizing, dyeing, drying, etc.

7.4.3 Agricultural Crops

India being predominantly an agro-based economy it is expected that large amounts of thermal energy will be needed for processing of various crops for safe storage and consumption. Drying, an important step in the processing, is energy intensive. However, commercial methods of drying using steam or hot air are practiced only for cash crops like tea, tobacco and cardamom, and the majority of crops are subjected to open sun-drying. Sun-drying, though the cheapest method available to

farmers, is known to be ineffective, causing damage to crops. Use of solar energy for drying operation is both feasible and desirable. In the following sections, the energy use patterns and the potential for solar applications in agricultural sector is discussed.

Rice Milling and Processing

In the processing of paddy to rice, paddy is first parboiled and then dried. Then the paddy is milled and husk is separated. The rice thus obtained is polished and the bran separated. The rice is graded, bagged and despatched. Bran and broken germs are bagged separately. In the traditional parboiling method, paddy is soaked in cold water for 36-48 hours and then steam is blown in separate tanks until the husk is slightly opened. In the modern method of parboiling, hot water at 65^{o}C to 70^{o}C or saturated steam is used to raise the moisture content of the paddy, and the paddy is then soaked for 2-3 h. The product is then dried in mechanical driers at about 50^{o}C. According to a study, the quantity of steam required at 4 kg/cm^2 (g) for heating water (for soaking) and steaming is about 0.2 t/t paddy processed.

Tobacco

Tobacco curing is an important process that decides the colour and aroma which in turn determines the quality of tobacco used for cigarette manufacture. The curing process involves the following stages : (i) yellowing (ii) colour fixing (iii) leaf drying and (iv) stem drying.

In the yellowing stage which requires 30-40 h, green leaves are subjected to a temperature change from 30^{o}C to 40^{o}C in a gradual manner. Colour fixing involves removal of moisture from the leaves and during this stage the temperature is slowly increased from 40^{o}C to 50^{o}C over a period of 5-10 h. After this process, leaves are dried at temperatures maintained between 50-60^{o}C for 35-40 h. The last stage is drying of stems in which the temperature required is 70^{o}C. The time required for this process is 20-30 h.

For all these processes, coal or firewood is normally used as fuel. It is estimated that 4.5 kg firewood or 2.8 kg coal, equivalent to about 13,500 kcal of thermal energy would be required to obtain 1 kg of cured tobacco. Thus, it is clear that the temperature levels required for the curing of tobacco are well within the range obtainable using flat-plate collector technology.

Coffee

The drying of coffee needs considerable quantity of thermal energy. Coffee beans are processed by two methods - the wet process and the dry process. In the wet process, the cherries are pulped, fermented (or mechanically hulled), treated with chemical reagents, dried and graded. In the dry method, the cherries are dried from a moisture content of 60-65 per cent to a final moisture content of about 10 per cent in various stages. Open sun-drying, electrical drying and mechanical drying are all in use. The temperatures needed are below 45°C which can be easily achieved by the conventional solar collectors.

Cardamom

Cardamom is an important export-oriented crop and cardamom curing requires large amount of thermal energy. Open sun-drying is not practiced as it bleaches the green colour of cardamom. It has been shown, both by surveys and by heat transfer analysis that the existing methods of cardamom curing are very inefficient and consume large quantities of fuelwood. The temperature required for curing of cardamom lies between 50-60°C which is again attractive for solar energy applications.

Tea

Tea is India's one of the most important export commodities. India leads the world market with nearly 50 per cent of the total world production. Large quantity of thermal energy (3 kWh/kg of made-tea) is used in the processing of green leaf which involves the following operations: withering, rolling and cutting, fermentation, drying and sorting. Hot air below 100°C is used mainly for drying and to some extent for withering. The cost of generating heat for removing moisture from green tea leaves during withering and drying contributes most towards the cost of tea processing. Hence, there is a potential for application of solar energy in the tea industry.

Other Crops

There is a significant potential for solar energy applications in the drying of various other crops like chillies, spices, coconut, maize, sorghum, groundnuts, etc. all of which need hot air for drying below 70°C.

7.4.4 Food Processing

Consumption of processed food such as canned fruits and vegetables has shown a steady increase in India in recent years. Aerated beverages, fruit juices and squashes account for a major proportion (76 per cent of total produce), while canned fruits and vegetables form the rest.

Since the food industry covers a wide range of products, a variety of operations are involved in the processing of different products. These include sorting, grading, peeling (or cutting), bleaching, canning and heat sterilization.

Fruit processing involves extensive use of electrical as well as thermal energy. Thermal energy is used in the form of steam and hot water. In a recent study where some food processing units were surveyed to assess the use of steam and hot water, the amount of hot water used between 70^{o}C to 100^{o}C varies according to the products manufactured and plant capacity. Use of hot air at temperatures between 60-120^{o}C has been reported by some units. There seems to be a good potential for using solar heating systems in such industries, but there is a need to assess the extent of use of hot water and hot air in the industry as a whole.

7.4.5 Others

The other potential users of solar heating systems are (i) pulp and paper industry (ii) cigarette and bidi industry (iii) silk industry (iv) plywood industry and (v) hotel industry. For certain applications, (e.g., for cold storage and food preservation), use of solar energy for cooling by means of vapour absorption refrigeration system appears promising.

7.5 TECHNOLOGY

The types of devices used for collection of solar energy are: (i) shallow solar ponds (SSP) (ii) salt gradient solar ponds (SGSP) (iii) flat plate collectors (FPC) and (iv) evacuated tubular collectors (ETC). While the first three types of collectors are suitable for hot water/hot air generation below 90^{o}C, the ETC can generate steam at temperatures up to 150^{o}C.

SSPs are relatively less expensive devices for low temperature (approximately 60^{o}C) applications. They consist of shallow beds of water (10 cm deep) confined between two plastic layers, the bottom layer being black and the top layer transparent (see Fig. 1). A third clear plastic glazing is usually provided. A schematic diagram of shallow solar pond is shown in Fig. 1.

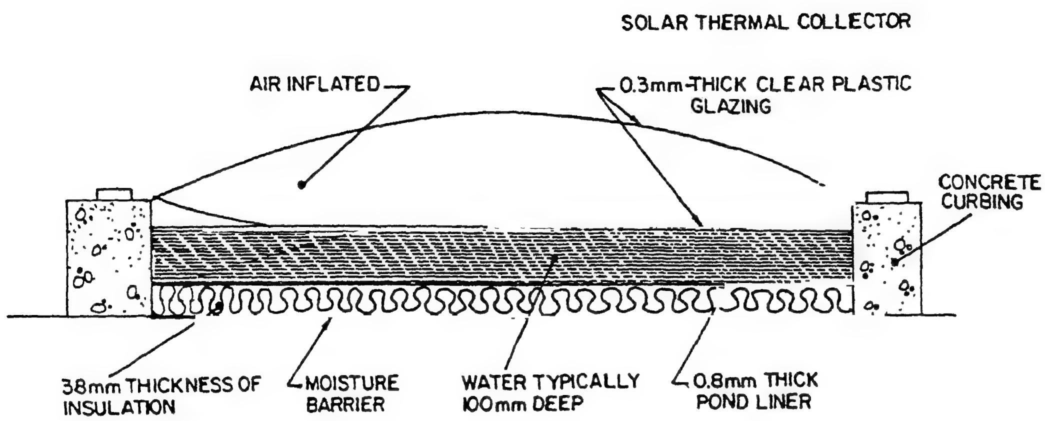

Fig.1: Schematic diagram of a shallow solar pond

The salt gradient solar ponds are large (surface) area solar collectors with in-built sensible heat storage systems. They are typically about 2.5-3.0-m deep, with a surface area of several thousand square metres. Solar energy received at the bottom of the pond containing saline water is absorbed in the mass of water and convection of heat from the bottom to the top layers is suppressed by artifically creating a density (or salt concentration) gradient across what is known as a non-convecting zone (NCZ). The thickness of the NCZ is typically about 0.8-1.0 m. The main advantage of SGSP is that they are several times cheaper than the flat plate collectors on a unit area basis. A case study for providing process heat to a dairy shows that for the same amount of heat delivered, the SGSP is about 5 times more cost effective than the FPC. The disadvantage of SGSP is that the technology is still at an experimental/demonstration stage and as such it is not available for prospective users. Figure 2 shows a schematic diagram of SGSP.

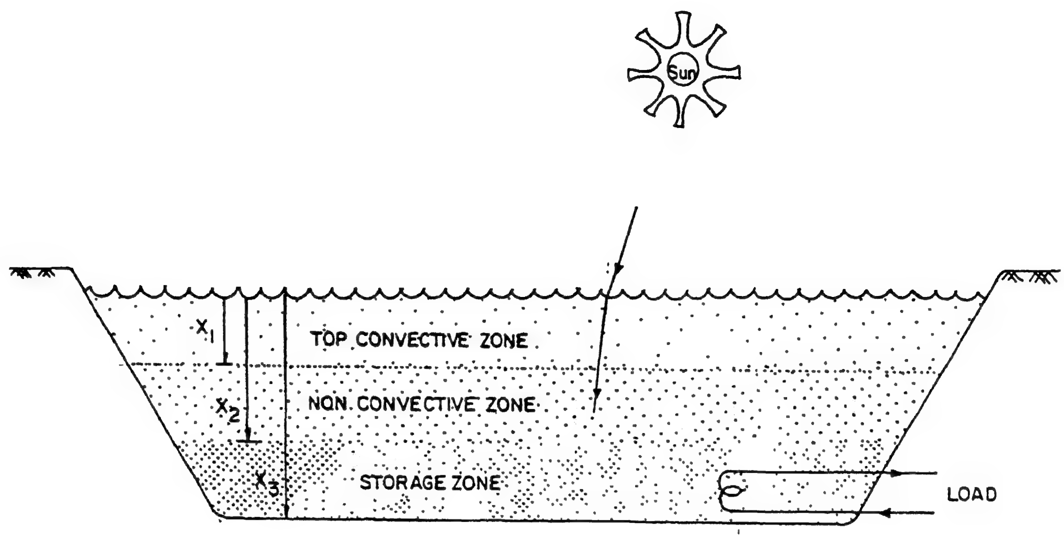

Fig.2: Schematic diagram of a salt gradient solar pond

The flat plate collector technology is now quite well developed in India and there are several manufacturers manufacturing these collectors (see Appendix 1). The FPC, (shown in Fig.3) consists of a fin and tube metal absorber painted black with insulation at the bottom and clear glazing at the top. A single collector typically has an area of about 2 m^2 and several collectors are connected in a series-parallel combination to form a collector bank. The collectors are south facing and are tilted from the horizontal at an angle approximately equal to the latitude of the place. Cold water enters the bottom header of the collector, gets heated, and the hot water produced is stored in insulated tanks for use. Apart from the collectors and storage tanks, the system consists of pumps, controls and piping. A back-up is usually provided for use during cloudy or rainy days and/or for heating the water further to the desired temperatures.

Solar air heaters consist of a blackened rectangular air duct with insulation at the bottom and clear glazing at the top. The hot air can be either directly used during sunny hours or can be diverted to charge a pebble-bed storage tank for use at a later time. The liquid collector systems often use heat exchangers to reduce the problems of corrosion of collector tubes.

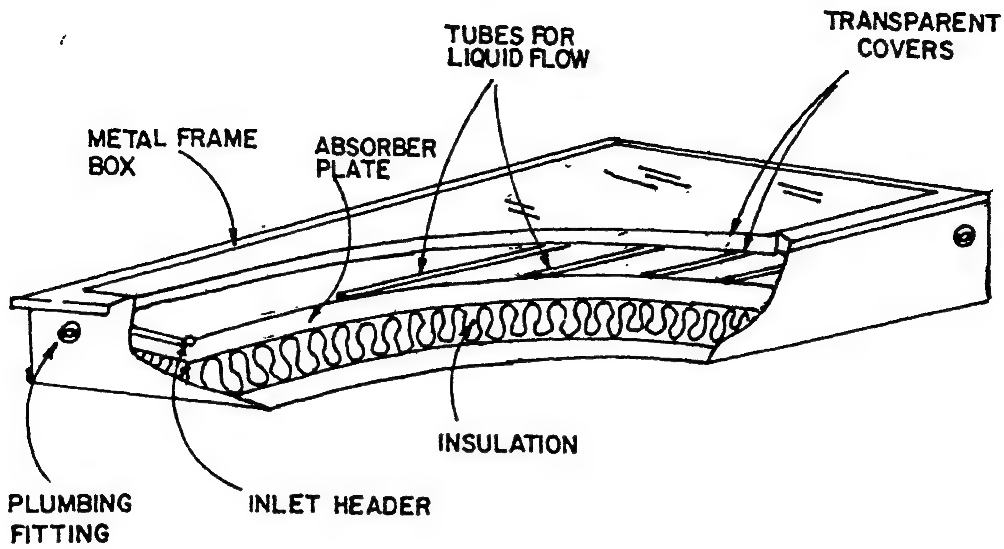

Fig.3: Schematic diagram of a flat plate collector

Several control strategies can be used to achieve best utilization of solar energy. Commonly used control strategy in India is to extract energy from the collectors only when the temperature in the collector exceeds a preset value. Though this method does not make the best use of available solar radiation, it is simple and inexpensive. A detailed schematic diagram of solar water heating system is shown in Fig. 4.

Design methods for obtaining the optimum area of solar collectors for a given application and for a given location are available. The useful energy output of solar heating systems varies throughout the year, being highest in summer (April-May) and lowest during the monsoon season (July-August). If the system is designed to meet the process requirements for the lowest radiation month, excess heat is delivered during summer conditions. On the other hand, if the system is designed to meet the process requirements for April-May months, a back-up system would be needed during monsoon or winter months. For the latter case, the yearly solar fraction, or the fraction of the total energy contributed by the solar energy in a year, will be less than 1.0. An economic analysis would finally decide the optimum solar fraction and hence the optimum area.

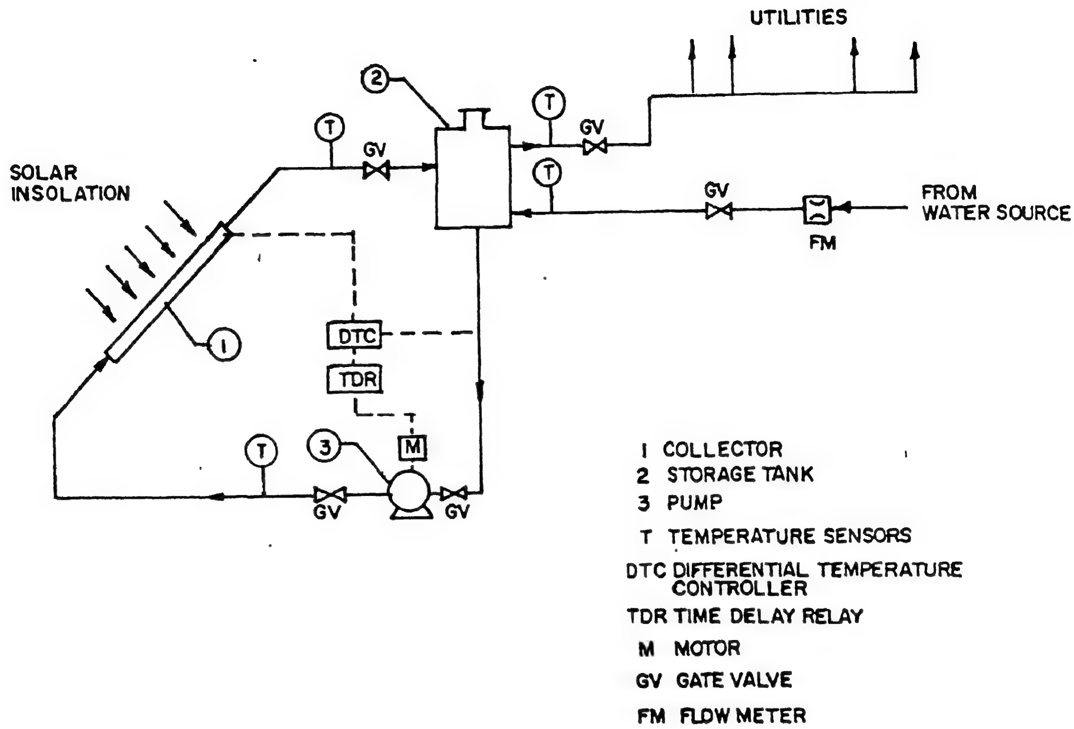

Fig.4: Schematic diagram of a control system for solar water heating system using FPCs.

Imported evacuated tubular collectors are commercially available in India. Indigenous collectors are likely to be available within the next few years. These collectors can deliver steam at temperatures up to 150^{o}C. As the low-pressure steam requirement in industry is much more than hot water/hot air requirement, there exists a certain potential market for these types of collectors provided the economics are favourable.

A schematic diagram of a concentrating type collector (central receiver concept) is shown in Fig.5, which are still in experimental stage in U.S.A.

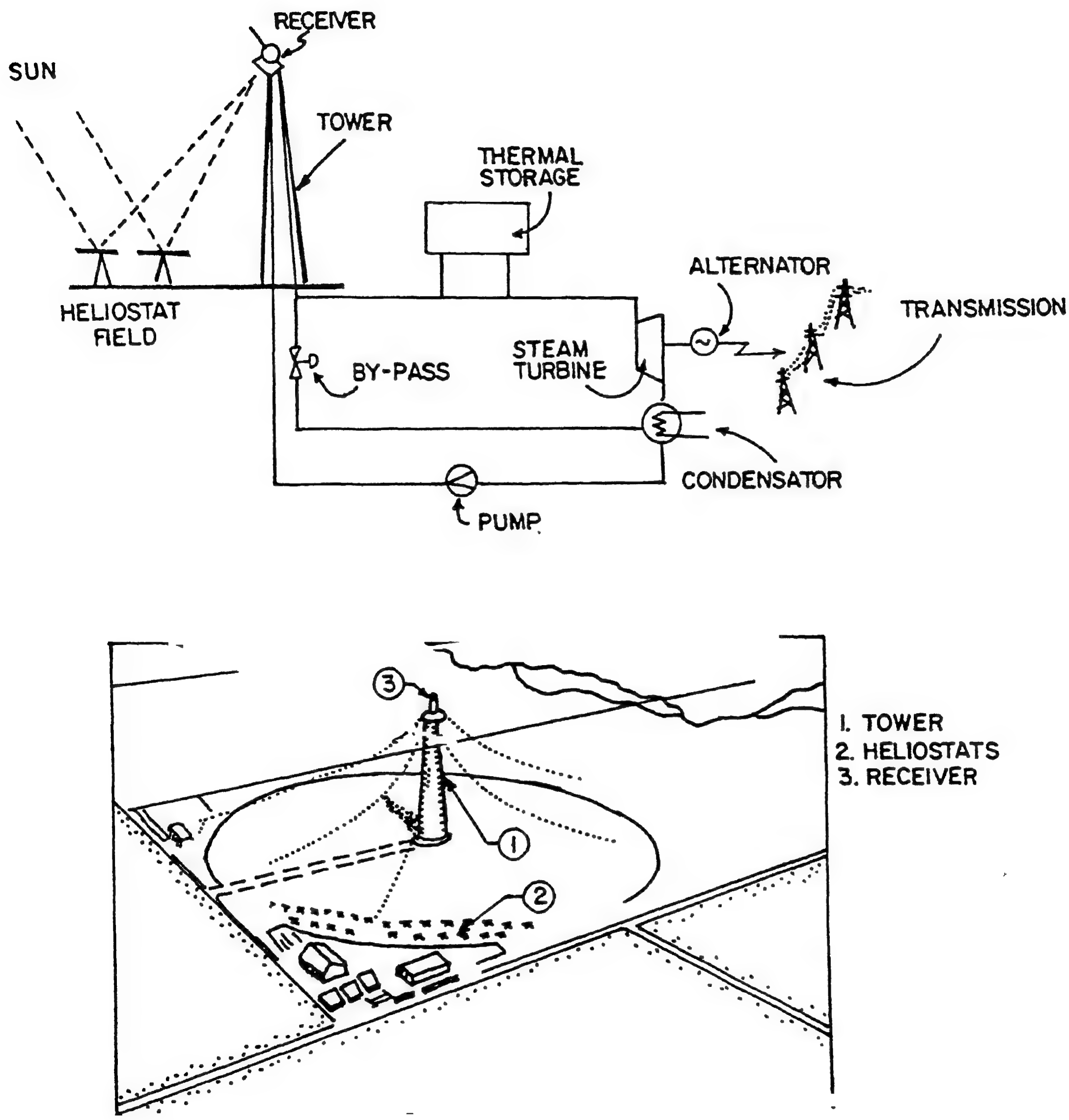

Fig.5: Schematic diagram of a concentrating-type collector

7.6 APPLICATIONS OF SOLAR PHOTOVOLTAIC (SPV) ENERGY CONVERSION SYSTEMS

The materials which generate electricity when light falls on them are termed photovoltaics. Tapping the solar energy by use of photovoltaics offers great opportunity for the mankind to overcome the current energy crisis. The technical feasibility of SPV is now well established but the economic feasibility for large-scale applications has not been established yet. However, for small-and medium-scale remote area applications they are being used as a reliable source of energy.

Following are some important features of SPV systems:

(i) Electricity is generated directly by the SPV power systems, without the involvement of any moving part.

(ii) The only 'fuel' required is the naturally available sunlight.

(iii) The performance and operation of SPV power systems depends on the local geographical, environmental and climatological factors.

(iv) The photovoltaic modules, panels and arrays can only generate electrical energy, as long as sunlight is incident on the active solar cell surfaces. But, they cannot store that generated energy.

(v) The SPV power systems are modular in nature. It is possible to enhance or decrease the installed power-generating capacity, if required, even after the system has been operational for some time. Due to the modularity, the cost per unit installed capacity is not very much dependent on the magnitude of the installed capacity of the power system. This is a feature which is not available with most conventional electricity-generating systems. This feature allows the installation of microwatt to megawatt capacity power systems, without large variations in the unit power cost.

(vi) The solid-state reliability of the solar cells in the SPV power systems ensures long and reliable operating life for them. The SPV modules have been claimed to have a life of more than 20 years.

(vii) The maintenance requirements of SPV power systems are minimal, and these can be met by local training of users.

(viii) Stand-alone and self-reliant SPV power systems are equally feasible just as it is possible to have centralized systems.

(ix) An SPV power system, designed to meet a specified set of climatological, load and other conditions, would perform differently if any of these specifications is altered for some reason, during its operation.

(x) Time taken for design, installation and commissioning of an SPV power system, is significantly less than that of a conventional fossil-fuel powered system of identical capacity, i.e., the gestation period is small.

(xi) The current state-of-the-art international photovoltaic technology demands rather large initial capital investments per unit installed capacity. In comparison, conventional fossil-fuel powered electricity-generating systems require much less (by factors as large as 5-10) initial capital investments.

From a study of the features peculiar to SPV and various categories of SPV power systems, it is clear that, under the prevailing conditions, the most appropriate industrial applications of SPV power systems would be in those areas, which satisfy either all or at least some of the following conditions:

(i) Availability of electrical energy by other reliable and cheaper means is not guaranteed at the place of use.

(ii) Logistics do not permit the transportation of fuels to the site for generation of electricity.

(iii) Round-the-clock availability of competent maintenance personnel at the site is not guaranteed.

(iv) Electricity requirement is small in magnitude.

(v) Reliability and timely availability of electricity, when needed, are more important than initial capital investments.

(vi) The load is preferably DC, and the losses in the load circuit are minimal.

(vii) The site has reasonable abundance of sunlight.

(viii) The load demand at the site matches the availability of sunlight there.

7.6.1 Types of Industrial Applications

There are a number of industrial and non-rural applications which satisfy either all or many of the above criteria. Some of them are listed below:

(i) Cathodic protection of long lengths of oil and other pipelines and metal bridges.

(ii) Signalling, telecommunication, lighting and many other applications in railways.

(iii) Telecommunication and telemetry applications in many usually-unmanned areas, such as highways, forest lodges and bungalows, arid and/or normally uninhabited areas.

(iv) Unmanned information collecting stations, such as weather data collection platforms (DCP), meteorological stations, and offshore oil platforms.

(v) Various defence and service applications.

(vi) Consumer products, such as electronic pocket calculators, electronic watches, electronic games, portable radio, television receivers, etc.

Therefore, the industrial applications may be broadly divided into the following areas:

(i) Telecommunication and telemetry

(ii) Powering electronic equipment for data and information collection

(iii) Cathodic protection

(iv) Lighting

(v) Powering consumer electronics products.

7.6.2 Economics

In industry, an investment is considered to be financially attractive if the returns are greater than the initial cost and are recouped over a short period of time. While the principal advantage of using solar energy systems is that they reduce purchased electricity cost, their initial cost is high. In comparison, for a conventional system the initial cost is less but the operating cost is more. To compare the cost of a solar process heating system (primarily the initial capital cost) with future expected savings in fuel (due to less operating expenses), a detailed economic evaluation is needed.

The essence of life-cycle cost analysis is to sum the costs involved in operating a system over its expected life time and to compare such total costs for all viable, alternative systems to determine the best investment. In calculating the total costs over the system's life time, future costs are discounted appropriately as a function of time to recognize the time value of money so that the present value of future cash flows may be added together on a uniform basis*.

The net-benefits methods, as applied to solar energy, finds the difference between the life-time monetary savings from an investment in solar energy and its life-time costs. This is expressed by the following relationship:

$$NPV = \sum_{j=1}^{n} \frac{B-C}{(1+d)^{j}}$$

Where

B = Life-time savings (in 'n' number of years)
C = Life-time costs
d = discount rate
n = number of years the given system is expected to be operational

If the difference is positive, the investment is profitable. The method involves the same cost elements and arrives at the same conclusions as the life-cycle costing method, but it is formulated somewhat differently.

The benefit-cost method or savings-to-investment ratio (SIR) method is often used to evaluate solar energy investments. Like the previous method, this method is based on discounted cash flows. The SIR method, however, expresses savings and investment costs as a ratio rather than in monetary terms. The higher the ratio, the more the savings.

The internal rate of return (IRR) method calculates the rate of return an investment is expected to yield. Unlike the other methods, the IRR method does not consider pre-specified discount rate. Rather, the method solves for that rate of interest which when used to discount both costs and savings will cause the two to be equal, resulting in a net savings of zero. If the calculated rate of return is equal to or larger than the investor's minimum acceptable rate of return, the investment is considered profitable.

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* Refer to Chapter 8 for details on economic analysis of energy conservation measures.

The payback method finds the period of time that is expected to elapse before cumulative monetary savings from an investment in solar equipment will offset the investment costs. If the years and months to pay back are calculated to reflect the time value of money, the method is called discounted payback. If the time value of money is not considered, it is called simple payback. Though the payback method is used widely, it results in an incomplete evaluation.

Effective life-cycle costs to owners and users of solar energy equipment might be changed by governmental programmes designed to encourage adoption of solar systems. These programmes might offer special incentives such as tax credits, low-interest loans or subsidies. In India, for example, attractive subsidies are offered on solar systems. The net result of a subsidy programme is to effectively reduce the initial cost of the system to the owner. Life-cycle costing methods can still be used, taking the subsidy into account.

7.7 RECENT ADVANCES IN APPLICATION OF SOLAR ENERGY IN INDUSTRIAL PROCESSES

7.7.1 Destroying Toxic Wastes

Solar Energy Research Institute (SERI) researchers are taking advantage of the way light interacts with matter to destroy toxic wastes such as dioxins and pesticides. Their solar thermal process uses highly concentrated sunlight to convert toxins to non-hazardous by-products. It operates at lower temperatures and produces less carbon dioxide than conventional incineration techniques.

Using experimental reactors with the solar furnaces at Sandia National Whitesands Missile Range in New Mexico, U.S.A., SERI researchers have destroyed dioxin beyond detection limits - well beyond the stringent 99.99 per cent efficiency required by the U.S. Environmental Protection Agency (EPA). Test results were verified using certified EPA methods. High destruction efficiencies were also achieved for two common industrial solvents, viz., trichloroethylene and methylene chloride. Destruction occurs in a reactor at the focal point of a parabolic dish or central receiver, where wastes are bombarded by a beam of sunlight concentrated 500-1000 times and heated to temperatures of 750-1000^{o}C. Low-energy photons in the infrared and visible portions of the spectrum heat the waste. Then high energy photons in the ultraviolet region help to break the chemical bonds and destroy the molecules. Use of high energy photons has another benefit, process temperatures can be reduced by as much as 400^{o}C below those required for conventional incineration, leading to significant energy savings.

7.7.2 Solar Heat to Transform Metals

Alchemists of the Middle Ages dreamed of converting common metals to gold. SERI researchers have not quite accomplished this feat, but they are developing a solar thermal process that transforms metals into more durable and corrosion resistant substances.

Using a 25-kW solar furnace at Sandia National Laboratories in Albuquerque, New Mexico, SERI researchers have hardened steel from 250 to almost 700 microhardness units, making it suitable for high-abrasion tools such as metal cutters and stampers. Researchers have also used the solar furnace to melt and mix a nickel chromium powder into the top 0.5 mm of a steel test sample, creating a hard, corrosion resistant coating ideal for turbine blades and engines.

The transformation occurs as an intense beam of concentrated sunlight is focussed on the metal. A heliostat and a parabolic dish measuring 6.7 m in diameter can focus about 90 per cent of the incoming radiation into a beam just a few centimeters wide. As the beam scans the metal surface, the temperature quickly reaches 1000^{o}C or more. Surface layers may undergo a phase transition, as with transformation hardening, or they can melt and mix with the substrate, as with metallurgical bonding. Rapid cooling freezes the desired phase.

Because this innovative, energy-efficient process uniformly transforms larger areas than conventional techniques, it has already attracted the attention of several companies. SERI and the Mantech Development Company of Ft. Worth, Texas, are now investigating the radiative joining of metals for aeroscope applications.

Other applications may be possible, including zone melt recrystallization to create large crystals for electronics or photovoltaics, rapid thermal annealing, and photocatalytic reactions. To better explore these possibilities, SERI plans to build a solar furnace with a secondary concentrator to yield a more intense beam. This feature should help resolve issues of penetration depth and transition zone width for better metal products.

7.8 CONCLUSIONS

Based on Indian experience and on an analysis of solar IPH systems in U.S.A the following broad conclusions can be drawn:

- The potential for low-grade heat (< 100^{o}C) in industry is quite significant and has to be assessed properly for the Indian industry.

- The technology for solar IPH is simple and readily available.

- However, space is often a constraint for large solar systems.

- Since the contribution from solar energy to the total energy consumption in industry is small, it is not much concerned with the operation and maintenance of the system. In some cases it has been noticed that although the solar system is working satisfactorily, the hot water/hot air is not effectively utilized.

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CHAPTER 8

TECHNO-ECONOMIC EVALUATION OF ENERGY CONSERVATION MEASURES

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TECHNO-ECONOMIC EVALUATION OF ENERGY CONSERVATION MEASURES

8.1 INTRODUCTION

An energy management programme in an industrial unit would normally involve retrofits and process changes to be carried out to conserve energy. These measures could be identified by an energy audit. Once the technical feasibility of a project has been determined, the economic and financial viability need to be evaluated, since an industrial unit would normally like these to be ascertained prior to the actual implementation of the project. The financial analysis determines whether the project is to be supported from external or internal funds, or both.

Technical viability is evaluated using the following major criteria:

1. Is it technically possible to make the change and achieve energy saving ?

2. Will the change affect the operation of the equipment/ system adversely ? If so, is the effect of change within tolerable limits ?

3. Is the technical measure identified the most optimal one ? Are there other measures that are technically more attractive ?

4. What will be the effect of the (technical) change on other systems and equipment ?

5. Is there sufficient space available for installing new equipment ? Will the change affect accessibility of existing equipment ?

6. Does the energy saving have an impact of reducing load on utility equipment like boilers, and if so, what will the part-load characteristics be? Are these new characteristics acceptable ? If not, does it require additional changes ?

7. What are the new requirements on operation and maintenance of new equipment/system ? Are these simple to implement ?

8. If answer to any one or a combination of questions (depending on the particular measure) is negative, alternate methods of saving energy would have to be found.

In addition, the implementation of energy conservation programmes might require retraining of personnel and/or hiring experienced people, both for operation and maintenance.

8.2 ECONOMIC ANALYSIS

While many technically feasible alternatives can be suggested to a company during an audit, the litmus test for the adoption of any process lies in its economic viability. The major objective of any business (as assumed by mainstream economic theory), is that firms maximize profits. This does not imply an absence of non-pecuniary motives, e.g. to produce goods and services at least cost or to provide economically useful employment, etc. One normally finds that these are reflected in the long-term profit objectives of a firm. Profits in the long-term are generally considered more attractive as they reflect the ability of the company to survive. However, immediate returns are also required to ensure the smooth operation of daily transactions.

Often, within a business organization, the multitude and complexity of proposals that emerge are beyond the capability of a single person to assess adequately. Hence, the organization is broken down into sub-systems to evaluate proposals on a specific subject. A problem of the relative rating of proposals between the groups may arise, thus necessitating the establishment of an evaluation criterion against which all investment/ replacement proposals can be weighed. An evaluation criteria can be established on the basis of the relative importance given by the organization to each of the objectives. These objectives, weighed according to importance, become the measure against which the effectiveness of each of the alternatives are measured. If all the objectives are tangible, the economic evaluation is simplified as these tangibles can easily be converted into monetary terms. In this case, the relative rupee values are the weights for the different objectives. Monetary comparisons can be used when the intangible factors are relatively unimportant or in cases where the conversion to monetary terms has little impact on the effectiveness of the alternatives. In short, an attempt should be made to develop evaluation criteria which are distinct, mutually independent and additive. However, it should be borne in mind that any attempt to use the objectives of an organization as a criteria for evaluating alternative proposals will face the following problems.

1. The objectives in themselves would not provide a guide to choosing the optimum alternative, as all of them cannot be met by any one alternative.

2. Due to the unwieldiness and complexity of large-scale management systems, proposals are dealt with at the sub-systems level and, hence, the objectives of the organization might get diluted.

An estimate of future costs or benefits involves a forecast of future conditions. The value of money at different points of time depend upon the interest rates and time spans involved. Therefore, the present value of future costs and/or benefits has to be calculated.

The present worth of any future income or expenditure involved can be calculated from the compound interest formula, i.e.,

$$F = P(1+i)^n$$

where P is the principal
F is the future sum
i is the rate of interest
n is the number of interest periods from the present.

In the formula, the principal P is regarded as synonymous to the present value of an asset and F is its value after n time periods.

Example 1: What is the present worth of Rs. 100, 3 years from now, at an interest rate of 5 per cent.

$$F = P(1+i)^n$$

$$P = F \left(\frac{1}{(1+i)}\right)^n$$

$$= 100 * \left(\frac{1}{1.05}\right)^3$$

$$= \text{Rs. } 86.38$$

Now to determine the compound amount in a fund, a new variable A, i.e. the single-end-of-period payment, would have to be introduced. F now implies the total sum of money, and would be given by

$$F = A[1+(1+i)+(1+i)^2+\ldots\ldots\ldots\ldots+(1+i)^{n-2}+(1+i)^{n-1}] \quad (1)$$

Multiplying both sides by (1+i), we get

$$F(1+i) = A\ [(i+i)+(1+i)^2+(1+i)^3+\ldots\ldots+(1+i)^{n-1}(1+i)^n] \quad (2)$$

Subtracting (1) from (2), we get

$$F(1+i)-F = A[(1+i)^n-1]$$

$$Fi = A\,[(1+i)^n-1]$$

$$F = A\left[\frac{(1+i)^n-1}{i}\right]$$

Example 2: If a sum of Rs. 100 is deposited at the end of each year for 4 years in a bank account, which gives an interest rate of 4 per cent annually, how much money will be there in the account at the end of 4 years, assuming no withdrawals are made during the period.

$$F = A\,\frac{(1+i)^n-1}{i}$$

$$= 100\,\frac{(1+0.04)^4-1}{0.04}$$

$$= 100\,\frac{1.1699 - 1}{0.04}$$

$$= \text{Rs. } 424.6$$

The same formula is now used to calculate the capital recovery factor.

$$F = A\left[\frac{(1+i)^n-1}{i}\right]$$

$$\text{or} \quad A = F\left[\frac{i}{(1+i)^n-1}\right]$$

Also $F = P(1+i)^n$

$$A = P\left[\frac{(1+i)^n\, i}{(1+i)^n-1}\right]$$

$$\text{or} \quad \frac{A}{P} = \left[\frac{i(1+i)^n}{(1+i)^n-1}\right] \text{ or } \frac{i}{1-(1+i)^{-n}}$$

A/P is the capital recovery factor and refers to annual uniform repayments of a loan with interest being charged on the unpaid balance of the loan.

Example 3: If a sum of Rs. 10,000 is lent with the understanding that will be repaid - principal sum inclusive of interest at 4 per cent on all unpaid balances - in uniform annual payments, how much should be paid at the end of each year for 5 years ?

$$A = P \left[\frac{i\,(1+i)^n}{(1+i)^n - 1}\right]$$

$$= 10{,}000 \left[\frac{0.04\,(1.04)^5}{(1.04)^5 - 1}\right]$$

$$= \text{Rs. } 2{,}246.27$$

8.3 DEPRECIATION

The utility and value of most equipment tends to decrease with use and with the passage of time, i.e. it depreciates. For production to continue, the equipment would necessarily have to be replaced. Hence what most companies do is to set aside a certain amount for this 'consumption of value' of the capital asset known as the depreciation allowance. The purpose of computing a depreciation allowance is to (a) put a charge on the operating expenses of the firm so that profit reflects capital consumption costs and (b) to provide for recovery of capital consumption costs at a future date.

Depreciation can broadly be classified into two categories: (1) natural obsolescence (or physical depreciation), i.e. when the life of the asset is exhausted (2) forced obsolescence, i.e. when a new technology forces out the old one despite the old assets not being ready for disposal. Hence the estimated life as well as the number of years of use of the asset under consideration is an important determinant. Economic depreciation occurs when either (1) or (2) or both take place. However, it must be clarified that depreciation when used for accounting purposes differs from the actual depreciation that occurs in the economic or physical terms.

Depreciation is calculated on an annual basis since most companies prepare their financial statements once a year. There are several methods used to calculate the annual depreciation. Here, four cases/methods are described.

1. Straight-line depreciation: In this case, the annual depreciation charge is assumed to be equal over the entire life of the asset. The cost less the salvage value is divided by the expected life of the asset to arrive at the annual depreciation charge.

In the text, salvage value refers to the expected value of the asset when its economic life is over.

$$\frac{P - S}{L} = \text{Annual depreciation charge}$$

where P = cost of asset
S = salvage value
L = life

The straight line depreciation is 1/L

The book or accounting value of an asset can be ascertained from a firms' balance sheet, which is prepared in accordance with the accepted accounting concepts and conventions. In a balance sheet, the assets are generally shown at original cost minus depreciation. for several reasons, the real worth of an asset might change with time, but the accounting measurement of assets does not necessarily show the real worth or the current market value. Hence, the book value at the end of the N-th year can be calculated by

$$P - \left(\frac{P-S}{L}\right)N$$

Example 4: Consider a machine A which costs Rs. 8,000 installed with an estimated salvage value of Rs.500 at the end of 8 years.

$$\text{Annual depreciation charge} = \frac{8000 - 500}{8}$$

$$= \text{Rs. } 937.5$$

Straight line depreciation 1/N = 1/8 or 12.5 %

Book value at the end of the 5th year

$$= 8000 - \frac{8000 - 500}{8} * 5$$

$$= \text{Rs. } 3,312.5$$

2. In cases when the amount of depreciation is specified for the first year, the depreciation charge for the subsequent years is calculated on a straight line basis.

e.g., for the case of 30% depreciation in the first year,

Depreciation charge for first year $= 30/100 * (P-S)$

Annual depreciation charge in subsequent years $= \left[\frac{100-30}{100} \times \frac{P - S}{L - 1} \right]$

Example 5: If in the above case, the government permitted a 30 per cent depreciation in the first year, find the depreciation charge.

Depreciation charge for the first year

$$= \text{Rs. } 30/100 * (8000 - 500)$$
$$= \text{Rs. } 2,250$$

Annual depreciation charge for the subsequent years

$$= \frac{70}{100} * \frac{7500}{7} = \text{Rs. } 750$$

Straight line depreciation (for the remaining 7 years)

$$= 1/7 = 14.29 \text{ per cent}$$

Book value at the end of the first year would be

$$= 8000 - 2250$$

$$= \text{Rs. } 5,750$$

Book value at the end of the 5th year

$$= 5750 - \frac{5750 - 500}{7} \times 4$$
$$= \text{Rs. } 2,750$$

3. Declining balance depreciation: This method provides larger depreciation charges in the early years implying a quicker writing-off of the asset. The annual depreciation charge is calculated by taking a constant percentage of the declining undepreciated balance. This method will never depreciate the entire cost of an asset and presupposes a large salvage value.

   The book value or undepreciated balance can be calculated as follows. In the first year, the book value equals the cost of the asset. At the end of the first year, and for subsequent year-ends, the book value can be calculated by the following equations:

   Book value (N) = Book value (N-1) - Depreciation (N)

The depreciation charge can be worked out on the basis of the following method:

Depreciation(N) = [Book Value (N-1) * Depreciation Rate]/ No. of years since installation of the equipment

i.e., the amount of depreciation in any year equals the product of the book value of the previous year and the depreciation rate in that year, divided by the number of years the asset has been in service.

Example 6: Consider the installation of a machine B which costs Rs. 10,000, with an expected life of 5 years and with a salvage value of Rs. 500. Find the book value at the end of the first 2 years of the machine.

Depreciation rate = 1/5 or 20 %

Depreciation for first year = 10000 x 20/100 = Rs. 2,000

Book value at the end of the first year

= 10,000 - 2,000 = Rs. 8,000

Depreciation for the second year = (8,000 x 20/100)/2
= Rs. 800

Book value at the end of the second year = 8,000-800

= Rs. 7,200

4. Double declining balance depreciation: The method is identical to the declining balance depreciation except that in this case the rate of depreciation is doubled, i.e.

Depreciation (N) = Book value (N-1) * 2 * Depreciation Rate/No. of years

Example 7: Consider a machine which costs Rs. 10,000 to be installed with an expected life of 5 years and a salvage value of Rs. 500. Find the book value at the end of the first 2 years of the machine.

In this case the depreciation rate is 2x1/5x100 = 40 %

Depreciation for the first year is 10,000 x 40/100 = Rs.4,000

Book value at the end of the first year

= 10,000 - 4,000 = Rs. 6,000

Depreciation for the second year = (6,000 x 40/100)/2

= Rs. 1,200

Book value at the end of the second year = 6,000 - 1,200

= Rs. 4,800

In India, the most common method used to calculate depreciation allowances is the declining balance method. Since the government has stipulated that no other method of calculating depreciation will be recognized by the tax authorities, it is more by fiat than by convenience that this method is the one generally adopted.

8.4 PAYBACK PERIOD

When any investment decision is made, the economic viability of the decision can be tested using certain criteria. One factor which is of interest to investors is the length of time after which the money invested would be recovered or the payback period. The payback period can be calculated very simplistically by dividing the total investment expenditure on the equipment by the annual savings expected. The term annual savings has to be modified to net annual savings, in which case it encompasses a wider number of variables.

Net savings equals gross savings in the year less the costs incurred in that year. Savings could be in terms of energy consumption, labour requirements, etc. The number of units saved multiplied by their per unit cost would give the gross savings from an investment. Total costs cover a larger ambit. They are a function of the interest payments, capital cost, operation and maintenance (O&M) costs, tax, etc. i.e.,

Total cost (J) = Amortization (J) + O&M costs (J) + Equity payments(J) + Tax payments (J)

In the case of certain investments, a tax concession, known as a tax credit, is given to the investor . A tax credit is generally a fraction of the investment cost and is included as a deductible cost in the first year, i.e.the company is not taxed on this amount. The O&M costs are generally a fixed proportion of the investment cost and is added to the deductible costs.

During the first year, the deductible cost is calculated by

Deductible cost (1) = Interest (1) + O&M cost + Depreciation (1) + Tax credit

In subsequent years, the deductible costs are calculated by

Deductible costs (J-1) = Interest (J) + O&M cost + Depreciation (J)

The taxable income in any year is calculated by subtracting the deductible costs in that year from the gross savings in the same year. Hence, the tax in the year can be calculated, i.e., (taxable income in that year) * (tax rate).

Interest and debt repayment (amortization) calculations are done in the following manner. The cost of the loan multiplied by the debt fraction of the company [the debt fraction is (1- the fraction of equity)]. Amortization of the loan is considered to be in equal installments and so equals the amount of loan divided by the loan period. The balance of the loan is computed in the following manner.

Balance loan (1) = Amount of loan

Balance loan (J) = Balance of loan (J-1) - Amortization of previous year(s)

Hence the interest calculations can be done i.e.

Interest (J) = Balance loan (J) * interest rate on debt

At times, the interest on the loan may be capitalized. This implies that the interest due is added to the principle and this total is then amortized over the loan period. Through this method, the total amount repaid is higher than equal repayment installments, it is a useful repayment method for industries where operations stabilize after a couple of years. Additionally, since payments in the later years are worth less than in the initial ones, many companies prefer a later repayment of the loan.

Example 8: Assume a company borrows Rs. 100 for a period of 10 years at an interest rate of 10 per cent, with the interest being added to the capital.

Year	Interest	Capitalized loan	Amortization	Balance loan
1	10.00	110.00	11.00	99.00
2	9.90	108.90	12.10	96.80
3	9.68	106.48	13.31	93.17
4	9.32	102.49	14.64	87.85
5	8.78	96.63	16.11	80.53
6	8.05	88.58	17.72	70.86
7	7.09	77.95	19.49	58.46
8	5.85	64.31	21.44	42.87
9	4.29	47.16	23.58	23.58
10	2.36	25.94	25.94	0.00

The total amount repaid in this case is Rs.175.31 as against Rs.155.00, when the loan is repaid in equal instalments.

The cost of equity of the company has also to be determined. This is done by multiplying the fraction of equity by the total cost.

Hence, all the variables influencing the total cost have been determined. The company can also avail of an investment allowance or tax credit (mentioned above) on a specified percentage of the investment. At present the investment allowance is 20 per cent. This however, varies depending on the type of industry and its location. The cash flow in a year is equal to the gross savings in that year less the total cost in the same year.

Now an accurate estimate of the payback period can be made i.e.,

$$\text{Payback period} = \frac{\text{Cost of the investment}}{\text{Cash flow}}$$

Another method by which the investment decision can be evaluated is by considering the net present value of the project. In this case, the prospective annual revenues and costs of the investment decision can be compared at the minimum acceptable rate of return (MARR). The excess of discounted revenues over discounted costs will represent an extra profit above the minimum return required to justify the investment. This can also be calculated as the sum of the present worth of future revenues less expenses. This is known as the net present value (NPV) of a project. If the present value is positive, at the minimum acceptable rate of discount, it implies that the project is feasible. When comparing two or more projects on a one-to-one basis, the project which yields the maximum NPV at the current rate of discount, should be chosen as the best alternative. This method of determining the best project overcomes the problem of negative cash flows in any particular year.

A common type of situation in investment arises when an investment is made at the beginning followed by a series of varying cash inflows. In this case the expression for the present value of future income is :

$$NPV = \frac{X_1}{(1+i)} + \frac{X_2}{(1+i)^2} + \ldots\ldots + \frac{X_n}{(1+i)^n} - X_o$$

NPV = net present value

X_o = initial investment

$X_1, X_2, \ldots. X_n$ = Positive cash inflows in year 1,2,n

i = interest rate (as a decimal)

If all the X's are positive, NPV will always decrease as 'i' increases. The investment remains attractive as long as the NPV is positive. If the chosen discount rate is increased and the NPV comes down to zero, the rate of interest at this point 'i' is known as the internal rate of return (IRR). Computation of the IRR presents the third alternative to evaluate an investment. In this case, the investment which yields the highest rate of return 'i' would be the most preferred project.

Example 9: Calculate the payback period, the NPV and IRR from the following data:

Assumptions

total cost	Rs. 20,000
annual cash inflow	Rs. 12,000
O&M cost	5 % of capital cost
life	10 years
depr	straight line depreciation
tax credit/investment allowance	20 %
amount loan	60 % of net investment
interest rate(equity)	12 %
equity fraction	40 % of net investment
loan period	8 years
salvage value	Rs. 1,000
tax rate	50 %
interest rate(loan)	14 %

Solution:

O&M cost =5/100 * 12,000 = Rs. 600

$$\text{Depreciation amount} = \frac{20{,}000 - 1000}{10} = \text{Rs. } 1{,}900$$

Balance of loan (J) = Balance of loan (J-1) - Amortization

Interest (J) = Balance of loan * interest rate on debt

Deductible costs (1) = Interest + O&M cost +
(First year) Depreciation + Tax credit

Deductible costs (J-1) = Interest + O&M Cost + Depreciation
(Second year)

Taxable income (J) = Cash inflow - deductible cost

Tax (J) = Taxable income * tax rate

Cost of equity = Fraction equity * amount of loan

Total cost (J) = Interest + Amortization + O&M Cost + Equity + Tax

Cash flow (J) = Cash inflow - Total cost

$$\text{Payback period} = \frac{\text{Cost of investment}}{\text{Annual cash inflow}}$$

$$\text{Payback period} = \frac{\text{Capital Investment - Cash Inflow(1)}}{\text{Cash Inflow(2)}} + 1$$

The first method of calculating the payback period assumes all cash inflows to be equal; the second method assumes equal cash inflow from the second year onwards.

$$NPV = \frac{\text{Cash inflow (1)}}{1.12} + \frac{\text{Cash inflow (2)}}{(1.12)^2} + \ldots\ldots\ldots\ldots + \frac{\text{Cash inflow (10)}}{(1.12)^{10}} - \text{Initial Investment}$$

Balance	Year	Loan Amount	Interest	Deduct cost	Taxable Income	Tax	Cost of equity	Amort-ization	Total Cost	Cash Flow	Cumulative Cash Flow
Balln 1	1	12000	1680	8580	3420	1710	960	1710	25380	-9380	-9380
Balln 2	2	11970	1676	4576	7424	3712	960	1949	7622	4379	-5002
Balln 3	3	11696	1637	4537	7463	3731	960	2222	7914	4086	-915
Balln 4	4	11112	1556	4456	7544	3772	960	2533	8266	3734	2819
Balln 5	5	10134	1419	4319	7681	3841	960	2888	8689	3311	6131
Balln 6	6	8664	1213	4113	7887	3943	960	3292	9196	2804	8935
Balln 7	7	6585	922	3822	8178	4089	960	3753	9802	2198	11132
Balln 8	8	3753	525	3425	8575	4287	960	4279	10526	1474	12606
Balln 9	9	0	0	2900	9100	4550	960	0	6510	5490	18096
Balln 10	10	0	0	2900	9100	4550	960	0	6510	6490	24586

PV of project = -8375 + 3490.51 + 2908.64 + 2373.26 + 1878.89
(12 % return) + 1420.62 + 994.06 + 595.27 + 1979.75 + 2089.61

= Rs. 9355.598

The NPV of the project/investment at a 12 per cent rate of return is Rs. 9,355. Since the NPV is positive, the project is acceptable. However, this method of evaluating a project is generally adopted when comparing the investment benefits accruing from two or more projects.

Since the NPV is positive, to arrive at the IRR, we have to increase the rate of return on investment. The minimum acceptable rate of return is assumed to be 15 per cent (since market rate of interest is 12 per cent). Hence, the calculation proceeds by a method of trial & error till the sum of future streams of income less the initial investment is zero.

Assuming various rates of return the calculations are as follows:

i = 15 %	25 %	30 %	38.4 %
-8156.52	-7504.00	-7215.38	-6777.46
3310.78	2802.24	2590.83	2285.88
2686.90	2092.25	1860.01	1541.47
2135.14	1529.60	1307.51	1017.83
1646.27	1085.03	891.81	652.09
1212.27	735.06	580.93	399.00
826.14	460.86	350.21	225.94
481.81	247.27	180.68	109.49
1560.60	736.86	517.70	294.68
1604.23	696.86	470.77	251.70
7307.60	2882.03	1535.07	0.61

This implies that the IRR of the project is about 38.4 per cent. Since this is above the MARR, the project is economically feasible.

8.5 FACTORS AFFECTING SAVINGS

Energy conservation schemes can at times result in a ripple effect causing changes to take place in the entire system. These changes could result in either an increase or decrease in the projected savings. Therefore, it is necessary that while assessing energy conservation schemes or equipment, the total system be considered and a detailed evaluation made of the cost of modification. An estimate of the emergent savings is required but is plagued with uncertainty due to several reasons.

Energy conservation schemes are essentially based on one of the following concepts:

1. Reduction in energy requirement in the basic processing step

2. Cascading energy use

Process retrofit operations need to be carefully evaluated before deciding their economic viability. Several constraints related to service and operating conditions influence the potential for savings. Broadly, the uncertainties are (i) service conditions eg. electricity supply at the required frequency and voltage, (ii) operational constraints imposed both by improper operations as well as due to unforeseen practical limitations. In addition, the deterioration in efficiency of operations in subsequent years due to use of the equipment has also to be considered. Hence, in reality, the situation might be somewhat different and, perhaps, more complex. Even the costs of a one-to-one replacement of equipment might be inaccurate. For example, it is often thought that an oxygen probe is all that is required to control excess air in a process furnace. Therefore, the payback period would only be a few weeks. However, any of the following situations may exist/arise:

1. A change in excess air may result in shift in heat duty between the radiant and convection sections of the furnace. In case of a boiler, this may result in a reduction in the level of superheat.

2. The stack damper may be irreparably stuck and conrol of excess air may not be physically possible.

3. The burners may not be capable of operating at low excess air levels, leading to an increase in combustibles in the flue gas and a reduction in the efficiency of the furnace.

4. There might be an ingress of tramp air leading to erroneous indication of the actual air available for combustion.

To make provisions for some of the modifications that may be required to derive the benefit of the oxygen probe and to incorporate suitable instrumentation to ensure that there is no loss of combustibles, the investment required might be several times the cost of the oxygen probe, which was supposed to solve the excess air problem.

The example of excess air control is one of the most simple cases that can be cited. In industry, when considering energy conservation schemes, the problems are far more complex and are compounded by the requirements of integrating a large number of systems/subsystems. In order to realistically cost energy conservation schemes, it is essential that the entire system be carefully studied with respect to the changes that may be required to derive the maximum benefit from the installation of energy saving equipment/components.

When estimating the savings from a technical change brought about in the production process, one parameter which can be used as an index of the efficiency of operations is the capacity utilization factor (CUF), which is defined as

$$CUF = \frac{\text{Net annual output}}{\text{Rated capacity} \times \text{annual hrs of operation}}$$

Thus the underutilization of any equipment in terms of both capacity and hours of operation, results in lower efficiencies and hence a decrease in output levels.

For projects which have long gestation periods, the levelized annualized costs (LAC) are computed. The capital expenditure incurred over the construction period is inflated to the year in which operation commence. This is then annualized by multiplying it by the capital recovery factor. Total annual costs are obtained by summing the annualized capital costs and the annual O&M costs. This is then divided by the product of the plant load factor, the number of hours of operation (annual) and the size/ capacity of the plant.

Example 10: Determine the cost of power generation in a 2 x 210 MW thermal power station, where

a. Capital cost (Rs. lakhs)

Year 1	3750
Year 2	8370
Year 3	8970
Year 4	8000
Year 5	1190

b. Annual O&M cost (Rs. lakhs)

1. O&M of power plant	1050
2. Coal extraction	3090
3. Coal transportation	3370
4. Fuel oils	800
	8310

c. Life of equipment - 30 years

d. Capacity utilization 0.61 (@ 5350 hr/a) factor

e. Rate of discount - 12 %

Inflating expenditure in each year of construction to year the operation commenced, i.e. 6th year, we get

$$1.12 \times 1190 = 1.3 * 10^8$$

$$(1.12)^2 \times 8000 = 10.0 * 10^8$$

$$(1.12)^3 \times 8970 = 12.6 * 10^8$$

$$(1.12)^4 \times 8370 = 13.2 * 10^8$$

$$(1.12)^5 \times 3750 = 6.6 * 10^8$$

Capital cost in 6th year $43.7 * 10^8$

$$\text{Capital Recovery Factor (CRF)} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$= 0.124$$

CRF * Capital Cost = Rs.5431.21×10^5 = Annual Capital Cost

Total Annual Cost = Annual Capital Cost + Annual O&M Cost

$$= 5431.21 * 10^5 + 8310 * 10^5$$

$$= \text{Rs. } 13{,}741.21 * 10^5$$

$$\text{Generation} = 0.61 \times 5350 \times 2 \times 210 \times 10^3$$

$$= 13706.7 \times 10^5 \text{ kWh}$$

$$\text{Cost/Generation} = \frac{13741.21 * 10^5}{13706.7 * 10^5} = \text{Re. } 1.0025 \text{ /kWh}$$

In this chapter, an attempt has been made to introduce the various financial methods of evaluating a technical proposal. Financial analysis can be used as an evaluation criteria or as a tool to select/rank projects identified by an energy audit.

Projects

1. Perform a detailed cost-benefit analysis of one of the major energy conservation schemes implemented at your plant.

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CHAPTER 9

ENERGY CONSERVATION IN RAILWAY WORKSHOPS

CASE STUDIES

CHAPTER 9

ENERGY CONSERVATION IN RAILWAY WORKSHOPS

CASE STUDIES

9.1 BACKGROUND

In 1987-88, the Indian Railways spent approximately Rs. 160 crores on energy used in maintenance workshops, production facilities and for other non-traction purposes. As the magnitude of energy consumption is large, efforts to conserve energy and thus manage energy consumption at the workshops and production units become important. As many of the workshops are old, there will be large potential for saving energy. As a part of the training material prepared by the Tata Energy Research Institute, a team from TERI conducted case studies of energy consumption and conservation at the carriage and wagon workshops of the Indian Railways at Alambagh (Lucknow) and Jhansi. The case studies were conducted during the period October 21-24, 1990 at the above workshops. The case studies included collection of energy related data, study tour of the workshops and discussion with staff members on energy use and energy saving.

In this section, the details of the data collected, observations made, and preliminary recommendations and conclusions of the TERI team have been provided.

9.2 CARRIAGE AND WAGON WORKSHOP, ALAMBAGH

The carriage and wagon (C & W) workshop at Alambagh, Lucknow (Northern Railway) was established in 1867. The average out-turn is 190 units/month (1 unit = 4 wheels) of carriages and 400 units/year of wagons (i.e., a total of 220 units/month). It is primarily a carriage repair workshop where periodic (annual) and non-periodic over-haul of passenger coaches of the Northern Railway are undertaken.

The workshop is divided into the following repair shops:

i. carriage repairs
ii. wagon repair
iii. paint shop
iv. saw mill
v. blacksmithy shop
vi. machine shop
vii. wheel shop
viii. tool room
ix. millwright shop
x. welding shop
xi. electrical

The annual energy bill for the Lucknow workshop for 1989-90 was Rs. 87.6 lakhs of which 65.2 per cent (Rs. 57.1 lakhs) was for purchased electricity while 34.8 per cent was for fuels (mainly L.D.O. and coal).

9.2.1 Energy Use Pattern

The major energy source used is electricity. The total connected load is 7500 kVA. The average power factor is 0.87. Electricity is required mainly for running air compressors. There are 18 air compressors which generate compressed air at 4-5 $kg/cm^2(g)$. The major load is the motor load which accounts for 4930 kW while the lighting load is 722 kW. The workshop has 120 welding plants and has a significant requirement for oxygen and dissolved acetylene.

The workshop purchased 44 million kWh of electricity, 793.5 kL of L.D.O and 31.8 kL of H.S.D.O., during 1989-90. In addition, 720.9 tonne (t) of steam coal and 95 t of grade B (hard coal) were used during 1989-90. L.D.O. and coal are mainly used in the furnaces in the blacksmithy shop. There are 20 oil-fired furnaces in the Alambagh workshop.

9.2.2 Energy Conservation Efforts

The energy conservation measures initiated in the workshop have been mainly in the area of reduction in electricity consumption. The following measures have been undertaken:

(i) Of the 18 compressors, it was found that many were being run in off-load condition. Now only 5-6 compressors are being used to supply the same quantity of compressed air.

(ii) A set of capacitor banks has been added and the power factor has improved from 0.84 in 1988-89 to 0.87 in 1989-90. A further increase in p.f. to 0.9 has been achieved during the last few months by a similar measure.

(iii) In many repair shops a single large motor was being used to drive a number of equipment. Individual motors have been provided for each equipment. For example, in the saw mill, a single large motor for all the machines has been replaced by small individual motors at the machines. This has resulted in nificant energy savings.

(iv) In many of the shops a few translucent FRP sheets have been installed on the roof at regular intervals to provide daylight and reduce electricity consumption.

(v) Individual sections have been given responsibility for ensuring that lights and other electrical equipment are switched off when not required.

In 1987-88 the electricity purchased was 61.5 million kWh. In the next year a 11.4 per cent reduction in the electricity consumed was achieved (54.5 million kWh consumed in 1988-89). A further reduction of 19.3 per cent was achieved during 1989-90 (44.0 million kWh consumed in 1989-90).

9.2.3 Recommendations

(i) The lighting level in most of the shops during daytime was insufficient. This was specially true of the blacksmithy shop.

The minimum light levels should be ensured as sufficient lighting level leads to higher productivity and improved morale at the workshop. (see Table for recommended light levels). The floor of the smithy shop should be cleaned periodically as the black floors tends to absorb the light.

(ii) There is no metering of electricity consumed in the workshop. The total metering for the workshop is done at the U.P.S.E.B. sub-station.

It is essential that an energy meter (trivector) be installed at the incoming feeder to the workshop. It is necessary to have individual meters at different shops and also at major loads, e.g., air compressors.

(iii) In many of the compressor drives, the belts were slack. Some compressors were being run with less belts on pulleys than required.

It must be ensured that the compressors are run with the specified number of belts without any slackness (and the tightness of the belts must be checked for proper power transmission).

It should be evaluated if flat belts could be used in place of V-belts. Energy savings would range from 10-20 per cent.

(iv) Significant improvements can be made in the smithy shop. No temperature measurement is taken in any of the furnaces. Some furnaces have provisions for pyrometers but these were not working (probes and/ or instruments need to be replaced). The preheating arrangement provided in some furnaces is not working. The furnace doors do not close fully, the flame emerges out and significant heat losses occur. The oil valves on the burners are defective and do not close fully resulting in oil wastage. The workshop personnel informed the TERI team that the firebricks used were of poor quality.

The quality of insulation should be upgraded with high quality refractories and firebricks, and ceramic fibre.

(v) Records of the amount of L.D.O. being used were not being kept properly. A fixed amount of 2920 L/ day in the smithy shop based on calculated norms was being used for accounting purposes. A dip stick arrangement exists on the L.D.O. tanks but it is not being used.

The oil tanks and oil lines need to be cleaned. It is essential to monitor the oil consumption shopwise (preferably in every large furnace).

(vi) An energy conservation cell headed by the Deputy Chief Mechanical Engineer (Dy. C.M.E.) should be set up in the workshop with representatives from different shops. Targets should be established for different shops. Energy consumption, conservation efforts and achievements should be monitored periodically. Training and awareness programmes should be conducted for all employees of the workshop.

(vii) A detailed energy audit should be carried out, to identify specific energy saving measures.

(viii) Complete modernization of the workshop in the long-term is vital to bring about large energy savings.

9.3 CARRIAGE AND WAGON WORKSHOP, JHANSI

The Central Railway Carriage and Wagon Workshop at Jhansi has an average monthly out-turn of 2040 units of wagons and 36 units of carriages. The workshop was started in 1913 as a locomotive shop and converted in stages to a carriage and wagon workshop in the 1930s.

9.3.1 Energy Use Pattern

The energy used in the workshop during the last three years is shown in Table 1. The annual cost of energy during 1989-90 was Rs. 157 lakhs. Of this the major portion (67.7 per cent) was for purchased electricity. Furnace oil accounted for 15.8 per cent and steam coal accounts for 13.3 per cent of the total energy bill. The total connected electrical load is 13,854 kW and the average power factor during 1989 was 0.9.

From Table 1 it is evident that during the period 1987-90, there has been an overall decrease in the energy consumption. From 1987-88 to 1988-89, the electricity purchased decreased by 7.3 per cent. In the next year, there was a further decrease of 7.8 per cent in the electricity purchased. However, the annual coal consumption increased by 7.8 per cent during 1987-88 to 1988-89 and by 3.9 per cent in the next year. The furnace oil consumption decreased by 8.8 per cent from 1987-88 to 1988-89 and by 4.1 per cent in the subsequent year. A reduction of 17.6 per cent in H.S.D.O. occurred during 1987-88 to 1988-89 and an additional 15.9 per cent in the next year.

Table 1

Energy Use Pattern in Jhansi Workshop During 1987-'90

Energy Form	1987-88	1988-89	1989-90
Purchased Electricity (10^6 kWh)	102.9	95.4	88.0
Cost (Rs.lakhs)	96.3	101.7	106.3
Self generated electricity (10^6 kWh)	2.2	3.0	2.3
Steam coal (t)	6539	7118	7411
Cost (Rs.lakhs)	18.4	20.0	20.8
Hard coke (t)	321	274	266
Cost (Rs.lakhs)	3.4	2.9	2.8
Furnace oil (kL)	979	893	856
Cost (Rs.lakhs)	28.4	25.9	24.8
H.S.D.O. (kL)	40.4	33.3	28.0
Cost (Rs.lakhs)	0.82	0.68	2.13

Contd.

Table 1 (Contd.)

Energy Use Pattern in Jhansi Workshop During 1987-'90

Energy Form	1987-88	1988-89	1989-90
Petrol (kL)	2.26	2.04	2.18
Cost (Rs.lakhs)	0.05	0.05	0.15
Total cost (Rs.lakhs)	147.4	151.2	157.0

9.3.2 Energy conservation measures

An energy conservation cell had been constituted in May 1989. The G.M. Central Railway has fixed a target of reduction of 5 per cent over the consumption in 1989-90 to be achieved during 1990-91. The following energy-saving measures have been undertaken:

(i) Capacitors worth 900 kVAR have been connected to the system during 1989-90 and the power factor has been improved to 0.97. This has enabled the workshop to avail of a high p.f. rebate from the U.P.S.E.B.

(ii) Some of the high wattage incandescent lamps in the workshop have been replaced by 250-W high-pressure sodium vapour lamps. The planned replacement of lights will result in a saving of 1100 kWh per day. The illumination levels have been improved and standardized, and a luxmeter to check light levels is being used. An outlay of Rs. 22 lakhs has been set aside for lighting improvements.

(iii) Three time-switches have been provided. An additional thirty three time-switches are to be installed in the workshop. The investment is expected to be about Rs. 1.6 lakhs and an annual saving of about Rs. 1.5 lakhs is expected.

(iv) Nine energy meters of 11-kV rating have been provided in the sub-stations and the readings are being monitored. It is planned to fix a quota on electricity supply based on the readings. It has also been decided to provide one energy meter on each outgoing L.T. feeder.

A fixed monthly quota of 6,66,600 kWh has been allocated for the workshop.

(v) Electronic ballasts have been fitted on some tube-lights.

(vi) Six energy-saving devices for the welding transformers have been bought. The device switches a transformer off it is not in use, i.e., when an arc is not struck.

(vii) Records are maintained for the use of oxygen gas and dissolved acetylene (D.A.). In the quarter ending June 1989, 106,188 Nm^3 of oxygen and 38,224 Nm^3 D.A. were used. During the same period in 1990, 106,587 Nm^3 of oxygen and 35,295 Nm^3 of D.A. was consumed. The average specific consumption of oxygen has been fixed at 27.32 Nm^3/unit and of D.A. as 9.7 Nm^3/unit.

(viii) Furnace oil (F.O.) used in different sections are monitored daily by means of dip stick arrangement. The average furnace oil used in the blacksmihty and spring shops is about 3000 L/day.

9.3.3 Recommendations

(i) Electricity consumption should be monitored shopwise. Separate metering should be done at the compressor house. This could be used for setting targets.

Decisions regarding the number of compressors to be operated at any time can be taken based on the actual loading.

(ii) Most of the temperature indicators (pyrometers) in the heat treatment section were not working as the defective thermocouple probes had not been replaced. The supervisors were aware of this but there seemed to be a problem with the stocking of these items.

(iii) Many of the furnaces were underloaded. A number of furnaces were being used for the same type of jobs.

It should be possible to sequence the furnaces so that less number of furnaces are used in a more optimal manner. This could result in significant energy savings.

(iv) A detailed energy audit should be carried out in the workshop to identify the energy use pattern and scope for energy-efficiency improvements.

(v) Awareness and training programmes should be conducted for all employees of the workshop, to raise the level of energy consciousness and expertise.

(vi) Complete modernization of the workshop is vital to bring about large energy savings in the long-term.

APPENDIX

THERMODYNAMICS

A.1 Introduction

Thermodynamics is the science that deals with heat and work and those properties of matter or substance that bear a relation to heat and work. Like all other sciences, the basis of thermodynamics is experimental observation. In thermodynamics, these findings have been formalized into certain basic laws, which are known as the first, second and third laws of thermodynamics. But before describing them in detail, some basic concepts and definitions related to thermodynamics are discussed below.

A.2 Concepts and Definitions

A.2.1 Thermodynamic System and Control Volume

A thermodynamic system is defined as quantity of matter of fixed mass and identity, upon which attention is focussed for study, e.g., a gas in a cylinder can be considered as a system. The term control volume is used whenever an analysis is to be made of a system that involves a flow of mass. Consider an air compressor, that involves flow of mass into and out of the equipment as shown in Fig. A1.

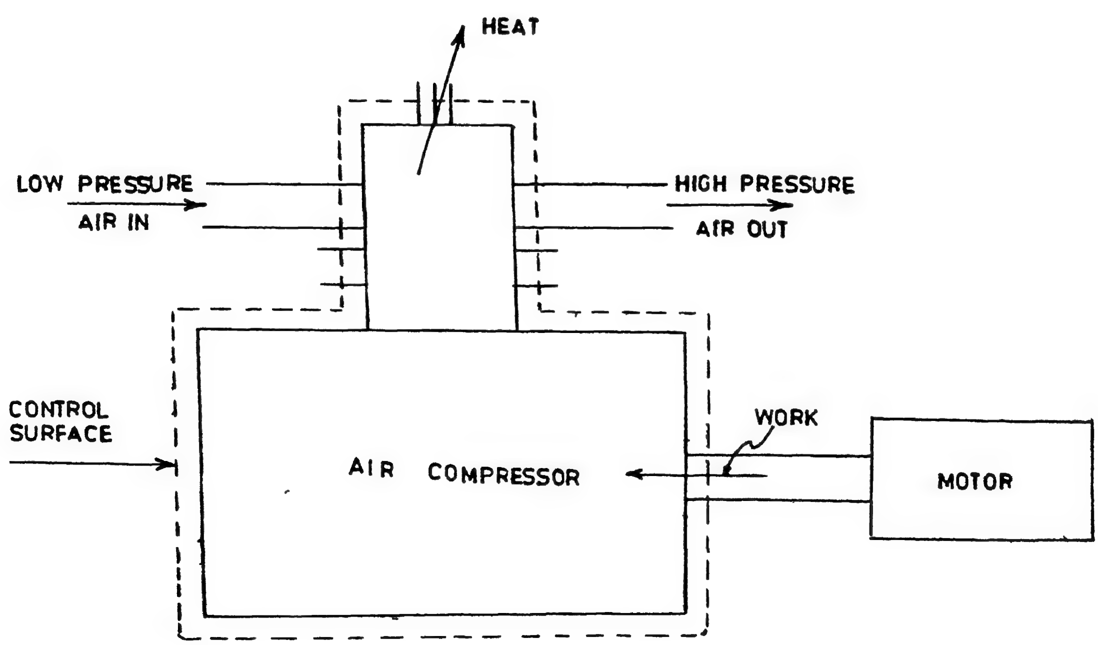

Fig. A1: Thermodynamic System and Control Volume

In this type of analysis, we have to specify the term control volume which is the volume that surrounds the device or equipment under consideration. The surface of this volume is referred to as the control surface.

A.2.2 Properties and State of Substance

Thermodynamic properties can be divided into two general classes, viz., (a) intensive (b) extensive properties.

An intensive property is independent of mass like pressure, temperature and density, whereas an extensive property varies directly with the mass like weight and total volume. For example, water exists in various forms. It may be vapour phase, liquid phase or solid phase. All these phases are the different states exhibited by water in different conditions of pressure, temperature and density.

A.2.3 Process

A process can be defined as the path of successive states through which the system passes.

A.2.4 Cycle

When a system in a given initial state goes through a number of different changes of state or process and finally returns to its initial state, we say that the system has gone through a cycle.

A.3 The Zeroth Law of Thermodynamics

It states that when two bodies have equality of temperature with a third body, they in turn have equality of temperature with each other.

For example consider two blocks of copper and a thermometer. Let one block of copper be brought into contact with the thermometer until equality of temperature is established, and then removed. Then let the second block of copper be brought into contact with the thermometer, and suppose no change in the mercury level occurs during this operation with the second block, then we can say that both blocks are in thermal equilibrium with the given thermometer.

A.3.1 Work

Work is usually defined as a force F acting through a displacement dx, the displacement being in the direction of force, i.e.,

$$W = F.dx$$

However, when treating thermodynamics from a macroscopic point of view, it is advantageous to tie in the definition of work with the concept of system, properties and process, e.g., work is done by a system if the sole effect on the surroundings (everything external to the system) could be the raising of a weight. Work done by a system could be considered positive or negative. For example a gas expanding against a piston is doing positive work whereas a piston compressing a gas is considered to be negative work. In general, if we consider work as a form of energy, we can conclude that positive work means energy is leaving the system, and negative works means energy is added to the system.

A.3.2 Heat

Heat is defined as a form of energy that is transferred across the boundary of a system at a given temperature to another system at a lower temperature by virtue of temperature difference between the two systems. Thus we can conclude that heat transfer occurs solely because of temperature difference between two systems. A body never contains heat. Rather heat can be identified only as it crosses the boundary. Thus heat is a transient phenomenon. It also follows that heat is identified at the boundary of the system, for heat is defined as energy being transferred across the system boundary.

A.4 First Law of Thermodynamics

It states that during any cycle a system undergoes, the cyclic integral of heat is proportional to the cyclic integral of the work. In other words

$$J \oint Q = \oint W$$

where J is a proportionality factor which depends upon the unit used for heat and work. Since in the international system of units, unit of work and heat is same, i.e., Joule, we can write -

cyclic integral (delta Q) = cyclic integral (delta W)

$$\oint \Delta Q = \oint W$$

A.5 Second Law of Thermodynamics

There are two classical statements of the second law, known as the Kelvin-Plank statement and the Claussius statement.

Kelvin-Plank Statement

It is impossible to construct a device that will operate in a cycle and produce no effect other than raising of a weight and exchange of heat with a single reservoir. In other words, it is impossible to construct a heat engine that operates in a cycle and receives a given amount of heat from a high temperature body and does an equal amount of work. Therefore, some heat must be transferred from the working fluid of a higher temperature to a lower temperature body. Therefore, two temperature levels are necessary for possibility of any work. As some heat is transferred from heat engine to the lower temperature body, we can conclude that it is impossible to build a heat engine that has a thermal efficiency of 100 per cent.

Claussius Statement

It is impossible to construct a device which operates in a cycle and produces no effect other than the transfer of heat from a cooler body to a hotter body. This statement is related to the refrigerator or heat pump. In effect it states that it is impossible to construct a refrigerator that operates without an input of work. The coefficient of performance is always less than infinity.

It is obvious that these two statements of second law are equivalent to each other or in other words violation of one statement will automatically lead to the violation of other. This can be illustrated with the help of an example as shown in Fig.A2.

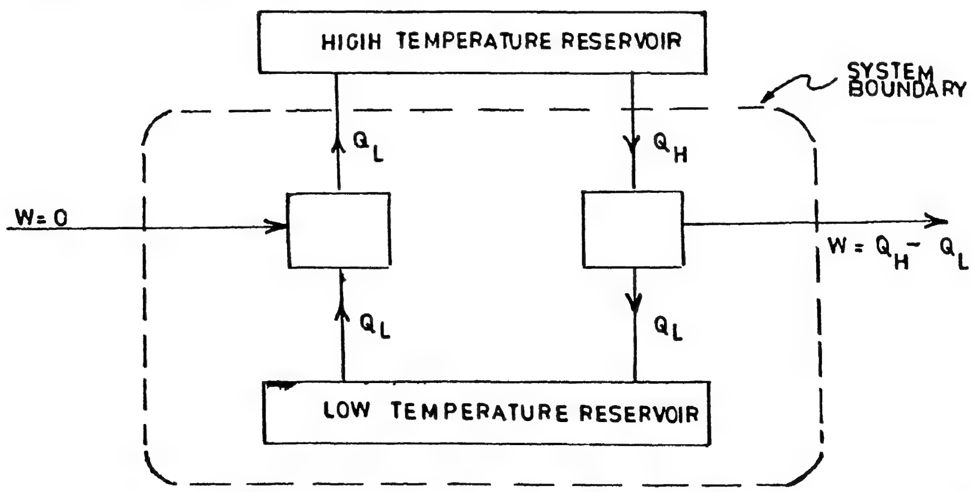

Fig. A2:Demonstration of equivalence of the two statements of the Second Law of Thermodynamics

In Fig.A2, the device at the left is a refrigerator that requires no work, and thus violates the Claussius statement. It is taking Q_L amount of heat from low temperature reservoir and transferring the same to high temperature reservoir. Let an amount of heat $Q_H > Q_L$ be transferred from the high temperature reservoir to the heat engine on the right, and let the engine reject the amount of heat Q_L as it does an amount of work $W = (Q_H - Q_L)$. Since there is no net heat transfer to the low temperature reservoir, the low temperature reservoir, the heat engines and the refrigerator can be considered as devices operating in a cycle and doing work = $(Q_H - Q_L)$ and the exchange of heat with a single reservoir. Thus there is a violation of the Claussius statement and a violation of the Kelvin-Plank statement.

A.6 Carnot Cycle

This can be defined as the most efficient reversible cycle which operates between given high temperature and low temperature reservoir. Since it is a reversible cycle, a heat engine working under this cycle can work as a refrigerator, if the cycle is reversed. This cycle can be shown on P-V (pressure-volume) and T-S (temperature-entropy) diagrams as in Fig. A3.

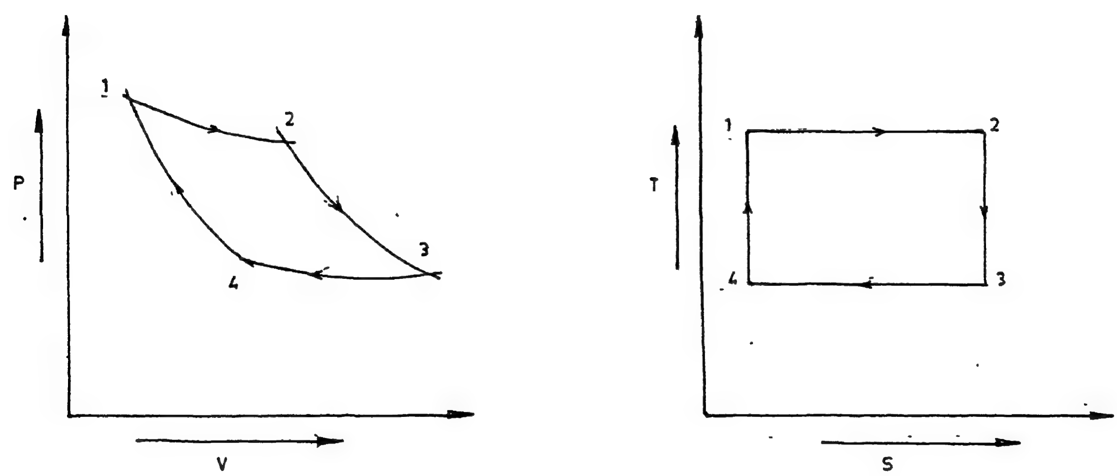

Fig.A3: Carnot cycle for a heat engine

1-2: Isothermal heat addition
2-3: Isentropic expansion
3-4: Isothermal heat rejection
4-1: Isentropic compression

A.6.1 Thermal Efficiency of Carnot Cycle

Thermal efficiency of any cycle can be defined as the ratio of work done during a cycle to the heat added to the system during a cycle, i.e.,

$$\text{thermal} = \frac{\text{Net work done}}{\text{Heat added}} = \frac{\text{Heat added - heat rejected}}{\text{Heat added}}$$

$$= \frac{R/J\,(T_1 - T_4)\,[\log_e {}^{V2}/_{V1}]}{R/J\,(T_1)\,\log_e ({}^{V2}/_{V1}]} = \frac{T_1 - T_4}{T_1} = 1 - \frac{T_4}{T_1}$$

Thus, the greater is the difference between T_4 and T_1, the greater is the cycle thermal efficiency.

Standard Carnot cycle is not practical as it is virtually impossible to achieve isothermal expansion or compression process in a machine operating at a reasonable rate of speed. Nevertheless, it is of value as a standard for comparing other cycles with it.

A.7 Rankine Cycle

The ideal cycle for a simple steam power plant is the Rankine cycle. The cycle comprises the following processes:

1-2 : Reversible adiabatic pumping process in the pump
2-3 : Transfer of heat in the boiler at constant pressure
3-4 : Reversible adiabatic expansion in the turbine
4-1 : Transfer of heat in the condenser at constant pressure

An ideal Rankine cycle in T-S co-ordinates is shown in Fig. A4.

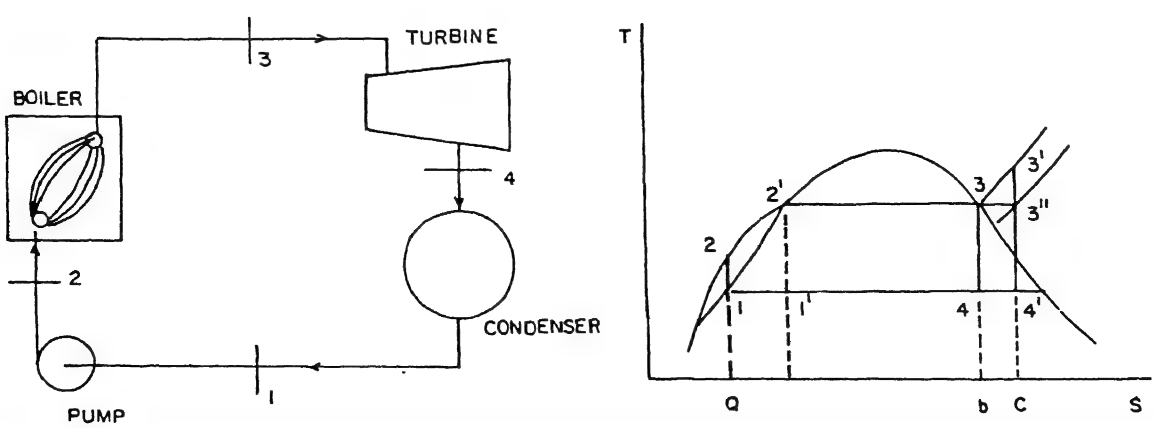

Fig.A4: Rankine Cycle in T-S coordinates

A.7.1 Efficiency of Rankine Cycle

Efficiency of Rankine cycle in the form of enthalpy and pump work can be written as:

$$\text{thermal (Rankine)} = \frac{(h_3 - h_2) - w_p}{h_3 - (h_{f1}+w_p)}$$

If pump work is neglected,

$$\text{thermal (Rankine)} = \frac{h_3 - h_2}{h_3 - h_{f1}}$$

A.8 Stirling Cycle

The Stirling cycle consists of a constant-temperature expansion, a constant-volume reduction in temperature and pressure, a constant-temperature compression, and a constant volume heating. This cycle has the same efficiency as the Carnot cycle. The Carnot efficiency can be achieved by including a regenerator in the cycle. The difficulties in achieving such a cycle are primarily those associated with heat transfer as it is difficult to achieve an isothermal expansion or compression in a machine operating at a reasonable speed and there will be pressure drop in the regenerator and a temperature difference between the two streams flowing through the regenerator. An ideal stirling cycle in P-V & T-S coordinates is shown in Fig.A5.

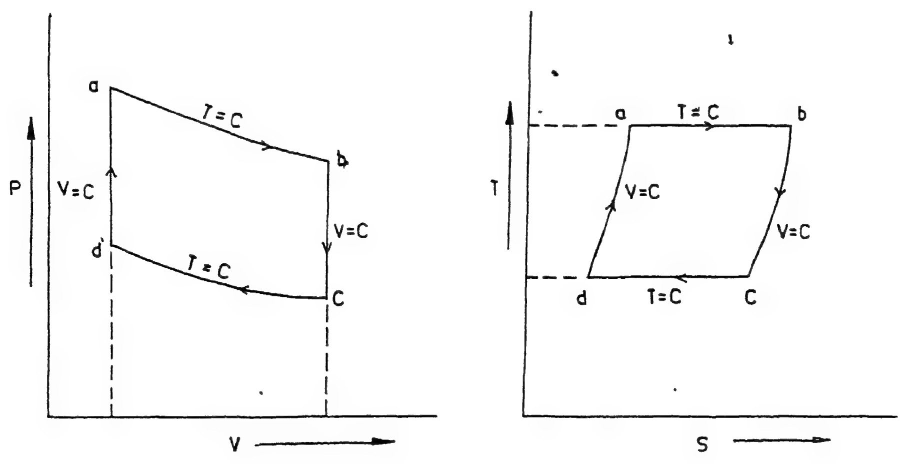

Fig. A5: Stirling cycle in P-V and T-S diagrams

a-b: Isothermal process
b-c: Constant volume expansion
c-d: Isothermal process
d-c: Constant volume compression

A.8.1 Stirling Engine

A Stirling engine is a thermal system that may be used to produce power from a high temperature heat source or as a refrigerator and heat pump to deliver energy at a higher temperature than that at the source.

Special Features

The following are some of the important features of a Stirling engine:

a) an external combustion Stirling engine operates at low pollution levels.

b) free piston Stirling engine is self starting

c) it does not require oil lubrication

d) it has got no gears

e) it has low loadings on the piston rings

A.8.2 Applications of Stirling Engine

A stirling engine may be used as a heat engine or a prime-mover receiving heat at high temperature from an external source, converting some to mechanical work and rejecting the balance as waste heat at low temperature. alternatively, they may be used as a refrigerating machine or heat pumps receiving heat at low temperature and delivering it at a higher temperature. Such machines require an input of mechanical work to accomplish their operation. In the refrigeration case, heat is normally received at a temperature below ambient and rejected at the ambient temperature. In the case of a pump, energy (heat) is normally extracted from a source at ambient temperature and rejected at a super-ambient condition. There is no intrinsic reason for this and stirling prime movers, refrigerators and heat pumps can operate in any temperature regime within the capability of the material of construction.

List of symbols used

f	force
h	specific enthalpy
x	distance
w	work
q	heat
j	proportionality factor to relate units of work to units of heat

h high
l low
s entropy
p pressure
v volume
specific volume
h_f enthalpy of water

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b. Research, development, application and demonstration techniques for more efficient and less polluting use of fossil fuels.

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